Statistical modelling of the frequency and severity of road accidents

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PREFACE

This dissertation presents my Ph.D. study with the title "Statistical modelling of the frequency and severity of road accidents" where an investigation of the under-reporting of traffic accidents in Denmark is conducted. The study has been carried out at the Department of Transport at the Technical University of Denmark in the period December 2009 to January 2016. The study was a part of a large research project named "Improving road safety" that was financed by the Danish Research Council.

First and foremost I would like to thank my supervisor Dr Sigal Kaplan for great motivation and inspiration. I have really enjoyed our many talks and discussions and I am forever grateful that our paths crossed. I would also like to thank my co-supervisor Professor Carlo G. Prato for methodology guidance and many interesting discussions. Both Sigal and Carlo's engagement and competencies have been crucial for this study and you both have my deepest gratitude for everything.

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Kira Hyldekær Janstrup, January 2016

ABSTRACT

Under-reporting of traffic accidents is a well-discussed subject in traffic safety and it is well-known that the degree of under-reporting of traffic accidents is quite high in many countries. Nevertheless, very little literature has been made to investigate what causes the high degree of under-reporting. The problem of under-reporting is not unique for traffic accidents as severe under-reporting is a challenge in many other fields of incident reporting. In other incidents fields with intended or unintended harm, research has investigated the behavioural reasons for why people choose to report an incident to the authorities. These kinds of studies have never been conducted within the field of transport. Furthermore, in other fields of incident reporting literature has documented that distrust to the police or to other authorities has an influence on the reporting rate. Even though a few studies have focused on the service quality within the police none have looked at the service quality specific for the handling of traffic accidents.

The objective of this Ph.D. thesis is to investigate the extent of under-reporting of traffic accidents in Denmark and trace the under-reporting systematically. As something new and innovative this project also explores the behavioural reasons for under-reporting by investigating the barriers associated with the intention to report a bicycle incident in Denmark. Furthermore, the service quality within the police for the handling of traffic accident reporting is investigated by an expert management tool.

Initially models were built by using existing traffic accident data collected by the police and emergency rooms in Denmark. The data registered by the police was collected on traffic accidents occurred on Danish roads in the period between 2002 and 2008. The emergency room data were collected at three hospitals located at Funen in the period between 2002 and 2009. Furthermore, two large-scale questionnaires were developed and administered. The first questionnaire was administered among bicyclist in Denmark and investigates the behavioural reasons for reporting traffic accidents. The second questionnaire was administered to stakeholders in the transportation field and was made to detect strengths, threats and opportunities for reporting traffic accidents within the police.

This Ph.D. study contributes significantly to the literature about under-reporting. The following innovative findings are presented:

1) New estimates of the under-reporting in the police registered data at Funen in Denmark have been found and these numbers were found to be larger than numbers found in other Countries (Paper 1).

2) As something new the heterogeneity in the reporting rate has been shown and by that recognition of the reasons for heterogeneity has been made, which in the end may lead to devising policy measures (Paper 1).
3) A connection between the occurrence probability of trauma type and crash, vehicle and person characteristics exists (Paper 2).
4) The ***attitudes that accident reporting is useless*** are found to be the most relevant factor related to the lack of intention to report future cycling accidents. Secondly, the factors: ***concerns about family distress and social image*** and ***preference to allocate time to other activities*** are both associated with non-reporting intentions (Paper 3).
5) New information about the barriers for the intention to report a bicycle incident can help in designing policy measures for improving the reporting rate for bicycle incidents and in that connection also the traffic safety for bicyclist (Paper 3).
6) A new and innovative method is found to evaluate the service quality and is tested on the handling of traffic crash reporting within the police (Paper 4).
7) Improvements can be made within the police to improve the handling of traffic crash reporting and these improvements will benefit the reporting rate the most if they are made in the dimension ***responsiveness*** (Paper 4).

The thesis extends the literature about under-reporting and gives new and innovative knowledge which can contribute to new policy measures for improving the reporting rate. For that reason this thesis should be used as an important tool whenever addressing the under-reporting challenge.

ABSTRACT IN DANISH (DANSK RESUME)

Mørketallet for færdselsuheld er et veldiskuteret emne inden for trafiksikkerhed og det er velkendt, at mange lande har et meget højt mørketal. Ikke desto mindre findes der meget lidt litteratur, der beskriver grundene til de høje mørketal for færdselsuheld. Problemet med mørketal er ikke unikt for færdselsuheld, og det viser sig, at høje mørketal også er et problem inden for mange andre områder med uheldsrapportering. Inden for andre områder med uheldsrapportering, både med tilsigtet og utilsigtet vold, har studier undersøgt, hvilke adfærdsmæssige grunde der får folk til at anmelde en hændelse til myndighederne. Disse typer af studier har aldrig været udført indenfor trafiksikkerhedsområdet. Inden for andre områder med uheldsrapportering har man også påvist, at mistro til politiet og andre myndighedsinstanser har en indflydelse på, om folk vælger at anmelde en uheldshændelse. Selvom kun få studier har fokuseret på servicekvaliteten hos politiet, har ingen specifikt undersøgt politiets håndtering af anmeldelser af færdselsuheld.

Formålet med denne ph.d.-afhandling er at finde mørketallene for færdselsuheld i politiets register i Danmark og spore systematikken i mørketallene. Som noget helt nyt og innovativt undersøger denne afhandling også, hvilke adfærdsmæssige grunde der er til, at cyklister i Danmark vælger at anmelde deres cykelhændelse/-uheld til myndighederne. Dette gøres ved at undersøge, hvilke barrier der har indflydelse på cyklistens hensigt om at anmelde en cykelhændelse. Afslutningsvis bliver servicekvaliteten af håndteringen af færdselsuheldsanmeldelser hos politiet også undersøgt, og her er et nyt redskab til at evaluere servicekvaliteten blevet fundet og anvendt på det konkrete problem.

Den første del af afhandlingen anvender matematiske modeller på eksisterende færdselsuheldsdata registreret af politiet og skadestuerne i Danmark. Data indsamlet af politiet indeholder alle færdselsuheld, som er anmeldt til politiet i perioden 2002 til og med 2008, og indbefatter de færdselsuheld, som fandt sted på offentlige veje i Danmark. Data indsamlet på skadestuerne indeholder alle færdselsuheld anmeldt til skadestuerne på Fyn i perioden 2002 til 2009. Den anden del af afhandlingen anvender data indsamlet via to store spørgeskemaundersøgelser. Det første spørgeskema henvender sig til cyklister i Danmark og undersøger de adfærdsmæssige grunde til at anmelde en cykelhændelse til myndighederne. Det andet spørgeskema klarligger styrker, trusler og muligheder for håndtering af færdselsuheldsanmeldelser hos politiet.

Denne ph.d.-afhandling bidrager signifikant til den eksisterende litteratur vedrørende mørketal for færdselsuheld, hvor følgende innovative hovedresultater præsenteres:

1) Mørketallet for de af politiet registrerede færdselsuheld på Fyn er blevet fundet og er større end de værdier, der er fundet i andre lande (Artikel 1).
2) Som noget nyt er der blevet påvist heterogenitet i færdselsuheldsregistreringen, og derved anerkendes grundene for heterogenitet i registreringen, som kan lede til misvisende politiske anbefalinger (Artikel 1).
3) Det er blevet påvist, at der er sammenhæng mellem specifikke traumatyper for trafikanter involveret i et færdselsuheld og forskellige færdselsuhelds- og personkarakteristika (Artikel 2).
4) Det blev påvist, at ***holdningen om at cykeluheldsrapportering er nytteløs*** er den mest relevante faktor for manglende rapportering. Efterfølgende er de mest relevante faktorer ***bekymring for, at det vil skabe uro i familien og skade ens sociale omdømme*** og at ***foretrække at bruge tiden på andre ting*** (Artikel 3).
5) Den nye information vedrørende barriererne for rapportering af cykelhændelser kan hjælpe med at udforme nye politiske målsætninger for derved at forbedre cykeluheldsregistreringen og ikke mindst trafiksikkerheden for cyklister (Artikel 3).
6) Der er blevet udviklet en ny og nyttig metode til bl.a. at evaluere servicekvaliteten for håndteringen af færdselsuheldsanmeldelser hos politiet (Artikel 4).
7) Det er blevet påvist, at der kan gemmeføres tiltag for at forbedre færdselsuheldsregistreringen i Danmark, og at disse forbedringer vil have størst indflydelse på antallet af rapporterede færdselsuheld, hvis de bliver lavet inden for dimensionen ***ansvarlighed*** (Artikel 4).

Afhandlingen bidrager til den eksisterende litteratur omkring mørketal for færdselsuheld og giver ny og innovativ viden, som kan bidrage til nye politiske målsætninger for at øge antallet af færdselsuheldsregistreringer. Derfor er denne afhandling et vigtigt redskab, når problemerne omkring mørketal indenfor færdselsuheldsrapportering skal løses.

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1 INTRODUCTION

1.1 ANALYSING ROAD CRASH DATA

Estimates have shown that 1.24 million road users die every year on the world's roads, and another 20 to 50 million sustain non-fatal injuries as a result of road traffic crashes (WHO, 2013). Traffic safety is a societal issue and all over the world guidelines are made in an attempt to improve traffic safety and thereby decrease the high fatality and injury numbers. Traffic safety is described as the science providing methods (and/or measures) to reduce the number of fatalities and injured road users in traffic accidents. The first known traffic accident with a petrol-engine car was in 1896, where the first known pedestrian died. In Denmark, the data registration of traffic accidents started in the 1930's and was initially collected by Statistics Denmark. In 1934, 100,000 cars were registered in Denmark and 14,000 traffic accidents were registered with 251 fatalities, 3,887 severe injured and 3,573 slightly injured road users. The highest number of traffic accidents in Denmark was in 1971, were 1,213 road users was fatally injured and another 27,587 injured. After this year a lot of rules were proposed to give better traffic safety (e.g. speed limit, seat belt, helmet). The Danish Road Directorate was established in 1949 and in 2003 they took over the handling of traffic accident data from Statistics Denmark. Among others, this was done to get a closer dialog with the police who was responsible for collecting the records. The goal for fatalities and injured road users in road crashes in 2012 on Danish roads were set to 200 persons fatally injured, 1,850 severely injured and 2,100 slightly injured (Færdselssikkerheds-kommissionens reviderede handlingsplan for perioden 2007-2012). Afterwards, National statistics from the Danish Road Directorate have shown that the goal was met for fatalities and slightly injured road users in 2012, but with 1,952 severe injured some efforts still have to be made on the area. At the same time, it is known worldwide that road crash databases often suffer from a high degree of under-reporting. A broad body of research has been made on the subject and even questioned the reliability of road crash data collected by the police (Elvik & Mysen, 1999; Farmer, 2003; McDonald et al., 2009). Severity and frequency models are often estimated on road crash data without consideration of the under-reporting phenomenon. However, in the last decade some more advanced models (e.g. Mixed logit, Nested logit, multinomial logit) have been used for severity and frequency modelling of traffic accidents (Haleem & Abdel-Aty, 2010; Geedipally et al., 2011; Malyshkina & Mannering, 2009; Kaplan & Prato, 2012) instead of the previous used Poisson regression and basic statistics (Shankar et al., 1997; Shankar et al., 1995; Lindqvist, 1991). These models prevent some of the many biases in traffic accident data (e.g. over- and under-dispersion, low sample size and mean) but not until recently these models have also been used to test whether or not they catch the huge under-reporting (Patil et al., 2012; Ye & Lord, 2011). In the study of Ye and Lord (2011) they concluded that neither of the models tested in their study (e.g. Multinomial Logit, Ordered Probit, and Mixed Logit) were immune to the challenge with under-reporting. Nested logit models seem to be even more vulnerable

when used on data which suffer from under-reporting. Recently, a study of Patil et al. (2012) has solved some of the problems but concluded that more testing is needed. So, even though advanced models find solutions to some of the problems with the huge degree of under-reporting, a lot of work and investigation is still needed in this area to minimize the problem.

1.2 UNDER-REPORTING

The problem of under-reporting is not unique to traffic accidents and severe under-reporting is present in many other incident fields (Probst & Graso, 2013; Fraas et al., 2014; Kääriäinen & Siren, 2011). The reporting problems have been addressed in different ways: (i) looking at multiple data sources, (ii) investigating behavioural reasons for reporting, (iii) evaluating service quality within authorities.

1.2.1 Road Crash data

The degree of under-reporting for traffic accidents is quite high in many countries, not only in low and middle-income countries (Abegaz et al., 2014) but also for high-income countries (Amoros et al., 2007; Reurings & Stipdonk, 2011; Martinez et al., 2012). In Scandinavia, the problem also exists and in a meta-study on incomplete accident reporting conducted by Elvik and Mysen (1999) the huge challenge was documented. Here they found that in Denmark only 21% of the estimated number of injured road users in traffic accidents is caught in the police recorded data. An ample body of research has shown that the highest degree of under-reporting is found among vulnerable road user (i.e. pedestrian, bicyclist, motorcyclist, moped users) (Elvik & Mysen, 1999; Sciortino et al., 2005; Yannis et al., 2014; Watson et al,. 2015). In Denmark, 17,500 cyclists seek medical care at emergency rooms every year, but only 10% of the cyclist accidents reported to the hospital have been recorded in the official accident data collected by the police (Elvik & Mysen, 1999). For light injuries and solo cyclist accidents (Kaplan et al., 2014) the degree of under-reporting gets even worse. The main public health challenge is the safety concerns connected with cycling and even though National statistics are often used to identify the factors underlying cycling accident frequency and severity, these studies are often limited to focus on bicycle accidents with motorized vehicles (e.g. Bíl et al., 2010; Klop, 1999; Kim, 2007).

Recent studies provide evidence that under-reporting is not randomly distributed among accident types but instead suffers from a selection bias (Amoros et al., 2007; Abay, 2015). The differences in data reported to police and/or hospital have only been investigated completely with severity degree and transport mode in mind. Very little literature has focused on some of the more social dependent variables such as gender, age and education (Stutts, 1990; Loo & Tsui, 2007; Watson et al., 2015) and even these studies point in opposite directions. More information on the difference between hospital and police reported data could be found, for example by using trauma type, and some studies have shown great potentials of knowing trauma type (Al-Momani, 1998; Adams, 2003; Martin et al., 2008). However, many of these studies have only focused on a small group of trauma (e.g. fatal, head injuries).

Even though hospital and police data are matched and used as a common source, an unknown number of road crashes are not reported to any of the authorities. Only a very limited amount of literature has focused on the area of none reported road crashes and the reason of this. In France, looking at the reasons people states for not reporting their accidents suggests that distrust in the police and reporting usefulness plays a role (Amoros et al., 2007). Nevertheless, the relationship between the choice to report an accident and human and social factors has never been systematic explored. The problem with under-reporting could be due to human and social factors as stated in Amoros et al. (2007), but it could also be because of the reporting procedure. Studies have tended to neglect an investigation or discussion of the advances and limitations in the way road crash data are collected. Therefore, while there exists some evidence of the relation between accident under-reporting, demographic variables and accident characteristics, there exists little or no information of the psychological and sociological factors underlying accident under-reporting.

1.2.2 Other incident data

Notably, the under-reporting challenge is not unique to traffic accidents, but it is rather a more general problem concerning incidents involving both unintended and intended harm. Severe under-reporting of a magnitude similar to traffic accidents has been observed also for incidents involving unintended harm such as work-related accidents (e.g., Probst & Graso, 2013) and sports injuries (e.g., Westman et al., 2010; Fraas et al., 2014). Severe under-reporting has been documented also for incidents involving intended harm, namely crime reporting with or without seeking medical help (e.g., Jones et al., 2009; Kääriäinen & Siren, 2011; Leshem et al., 2015). A broad sample of literature can be found on incidents reporting and about the psychological and sociological factors underlying the reporting. The Theory of Planned Behaviour (TPB) (Ajzen, 1991) has been used to discover these. The traditional TPB states that attitudes, social norms and perceived behavioural control are associated independently with the reporting intention. The TPB construct has among others been used to find factors influencing nursing staffs reporting intention on child abuse, pharmacists' intentions to report drug events and hockey players' reporting intention about concussion (Gavaza et al. 2011; Ben Natan et al. 2012; Kroshus et al. 2014). In the maritime transport and health-care sector, an important motivator for incident reporting is stated as the belief that incident reporting is useful for organizational learning, insight contribution and safety improvement achievement (Kongsvik et al., 2012; Lindsay et al., 2012). These studies and others also cite time constraints as major barriers to incident reporting, even in the case of severe consequences, because incident reporting systems are perceived as time-consuming to complete (Kongsvik et al., 2012; Lindsay et al., 2012; Williams et al., 2013; Winswold Prang & Jelsness-Jørgensen, 2014). The issue of social norms and their influence on reporting has been addressed for reporting of violent incidents and sports injuries (Kroshus et al., 2015; Leshem et al., 2015). Here, it has been found that lack of support from family and friends, feelings of guilt and shame, fear of family distress, perceived social image, and peer-pressure are associated with under-reporting. Distrust in the police was mentioned as a severe impeding factor to incident reporting in studies involving domestic violence and sexual assault (Jones et

al., 2009). Also, institutional trust was recently associated with attitudes regarding the usefulness of e-government services (Ozkan & Kanat, 2011). Last, a recent study showed that police distrust along with high societal trust is related to a low crime reporting rate (Kääriäinen & Siren, 2011). For that reason, there has been an increased focus on distrust and perceived service within the service sector (Brysland & Curry, 2001; Kumar et al. 2009; Catulli, 2012; Li et al., 2014). The police agencies have tried to overcome the increased distrust from public by increasingly recognizing that achieving public safety and security goals largely depends on establishing trust in the community via their role as public service providers in addition to the traditional law enforcement. Therefore, police agencies are becoming more consumer oriented, increasing their accessibility, quality of service delivery, staff commitment, accountability, and transparency (Drummond & Ensor, 2000; Cukier et al, 2012).

Different approaches can be used to evaluate service quality but quite many studies have used the SERVQUAL (Parasuraman et al., 1988) which is a model that identifies main components to measure service quality. Some studies have continued the work with the SERVQUAL and identified main components (dimensions) specific for police agencies (Mastrofski, 1999). Another method, Multi-Criteria Decision Analysis (MCDA), has mostly been used to assist in the evaluation process of projects and in the recent years also in many transport projects (Macharis & Bernardi, 2015). In the last couple of years, an increased interest of using the MCDA for evaluating service quality has been found for example in the health sector (Oddershede et al., 2014).

1.3 AIM AND CONTRIBUTION

The Ph.D. project focused on the degree of under-reporting on traffic accidents occurred on Danish roads and for that purpose, four complementary studies were made as described in Figure 1.

Figure 1.3.1: The progress of the Ph.D. study

The first study was made to understand the extent of under-reporting for traffic accident in Denmark and trace any systematic which may be connected with under-reporting and might be explained by socio-economic, person and crash characteristics. The second study was made to investigate the regularity in reporting and by a combining of data, a severity model was built. This study states the potential strengths by using two data sources instead of one. The first two studies in this thesis were made by the use of existing data, namely traffic accident data collected by the police and hospital supplied with some socio-economic data collected by Statistics Denmark. The third study derived from the results of the first and second study since the influence of the socio-economic characteristics indicate that there are some behavioural reasons

behind road users choice to report or not report traffic accidents. This study was based on data collected by a questionnaire among bicycle users in Denmark. This questionnaire group was selected because of the huge degree of under-reporting among bicyclists and the high increase in the number of bicycle users in Denmark. The last study made in this Ph.D. project was made to detect strengths, threats and opportunities for accident reporting within the police from stakeholders' point of view which means that the policy side of traffic accident reporting was investigated. Data used for this study was based on a questionnaire among stakeholders in the transport sector. The questionnaire aimed to evaluate the service quality within the police to detect what works in the system and where possible improvement can be made.

Together with the progress line of the thesis, there has been a huge development in the level of difficulty in the applied methods used. The first study used mostly simple calculations together with joint binary logit models. The second study used a more advanced discrete choice model, namely a mixed logit model with a single equation. The third study used a multi-equation regression to analyse the data and in the final study a combination of two methods, Multi-criteria decision analysis and Latent Class analysis, was conducted.

This thesis provides new knowledge of the extent of under-reporting of road crashes and by showing the heterogeneity in traffic crash data, it can be concluded that people cannot be treated as goldfish. For that reason, the systematic in under-reporting is investigated and social-economic characteristics were shown to have an influence on the degree of under-reporting. Therefore, as something completely new the behavioural reasons for road users' choice to report traffic accidents were investigated and thereby barriers, attitude and norms associated with the intention to report were revealed. This area was explored for the first time in connection with traffic accident reporting. Finally, the thesis provides a new methodology to evaluating service quality which is tested on the case of handling traffic accident reporting within the police. Again this study is the first, to our knowledge, to investigate service quality specific for handling of traffic accident reporting.

1.4 STRUCTURE OF THE THESIS

This thesis presents the background and motivation for the Ph.D. project and gives a detailed description of the main findings in each study made in the project. It is organized as follows:

Chapter 2 gives a detailed description of the data used in the study and classifies some of the problems with data.

Chapter 3 describes the theoretical framework and the different methods used for analysing the data.

Chapter 4 presents a description and main findings of each study conducted in this thesis.

Chapter 5 gives a discussion of the main findings

Chapter 6 contains the conclusion and highlight perspectives of this Ph.D. project.

The papers conducted in this study are all included in the end of the thesis.

2 DATA

Two of the articles in this thesis focused on police registered data, from Funen, and Emergency Room (ER) registered data collected at Odense University Hospital located at Funen. The third and fourth article applied data from large-scale surveys, one among bicycle users in Denmark and the other administered among decision makers working in the transport field in Denmark.

2.1 POLICE REGISTER

Traffic accident data for analysis and model estimation were extracted from the accident database maintained by the Danish Road Directorate. The data register is constructed by police records from traffic accidents, collected in twelve districts, which occurred on Danish roads during a 6-year period between 2002 and 2008.

In Denmark an accident is defined as a traffic accident if the following two conditions are satisfied (Vejdirektoratet, 2003):

(i) The incident occurred on a road, place or area which is used by regular traffic.
(ii) At least one of the involved road users is on wheel (i.e. truck, bus, tractor, car, motorcyclist, moped, cyclist).

This means that pedestrians falling or tripping on the streets are not included in the national road crash statistic. In Denmark, road users are not obligated, but can voluntarily report to the police or the hospital in case of any incident and the police are only obligated to document the road crash in a report, if one or more of the following five conditions are fulfilled (Vejdirektoratet, 2003):

1) Injuries occur.
2) Material damage exceeds 7,500 USD per vehicle.
3) A road user without a permanent address in Denmark is involved in the incident and there is made a claim for compensation.
4) The police is called to an incident where some of the involved persons are employed by the police.
5) The road user has made a law violation in a degree which should give occasion to later charge.

In circumstances where the emergency forces are called to the crash scene, the police officer in charge has the discretion to make the decision on final report documentation. For the decision process, police officers use reason and judgement regarding injuries, crash characteristics, perceived law violations etc. Therefore, many road crashes with only slight injuries and even some with severe injuries are not registered by the police.

In the police report each accident is given an id-number and every involved partner and road user, are linked to this number. The reports include codes on the level of injury severity for the involved road users, given on a 4-step scale (i.e., no (or minor)

injury, slight injury, severe injury, fatality). "*No injury*" corresponds to property damage or bruises, "*slight injury"* requires medical treatment, "*severe injury"* results in temporary or permanent incapacity, and "*fatality*" occurred within 30 days from the crash. The severity degree of the accident is given by the most injured road user involved. The data also consists of some crash characteristics, transport modes involved, crash location (e.g. intersection, motorway) and collision point(s). Information on the crash circumstances are also listed (e.g. condition of the surface, weather condition, speed limit at the concerned road). Last, some information on the involved parties in the crash is recorded (e.g. injury degree of the involved persons, age, gender, civil registration number, municipality) (Vejdirektoratet, 2003).

All the documentation is done by the police officers present at the crash scene and, therefore, it is dependent on the individual officers' estimate of injury. For this reason, the injury degree of the road users involved may not be the correct injury degree. Similarly, some of the reported crashes include only material damage but here there might be some self-treated injuries. To increase the reporting quality and accuracy, police officers attend regular training courses for handling road crash reporting. Furthermore, the officers receive a template with strict guidelines for crash reporting made by the Danish Road Directorate. After final documentation the police report is validated by the Danish Road Directorate and the crash location is linked with the Geographical information system. Upon finding inconsistencies or a mismatch, further consultation is conducted with the police (Vejdirektoratet, 2003).

2.2 ER REGISTER

All ERs in Denmark collect data about every injured person who visits the hospital or ER and these data are gathered in a large health dataset (LPR). In Denmark, the ERs are located in public hospitals, while private hospitals act as treatment facilities afterward a consultation at the ER or upon referral from the general physician. Every injured person is registered upon arrival to the ER, therefore the dataset also includes road users with no injury or just suspected injury. Notably, Denmark has a public health care system and thus the ER registration and the hospital admittance upon referral from a general physician are registered in the same database. Therefore, unlike in other countries, where multiple sources are needed to gather hospital records (Watson et al., 2015) in Denmark a single data source suffices.

The health data includes personal information about the injured (e.g., age, gender, personal registration number, address, accident date, date for registration, location of hospital, diagnose code) and of cause a contact-cause which is given by a 4-step scale (i.e., illness, accident, violence, suicide attempt). An activity code can also be found in the data, where transport is one of the activities (LPR, 2014). The Abbreviated Injury Scale (AIS) code is recorded as well, by the use of a 6-step scale, ranging from 1 "*minor injury*" to 6 "*fatality*") and listed for the three most injured regions of the body (Leth and Ibsen, 2010). Some diagnosis codes which relates to trauma type are also recorded and in this study the action diagnostic code is used. The action diagnostic code is listed for the diagnosis which are given after ended stay or treatment, and describes what

lead to the hospitalization, need of care or visit to the ER. This code is therefore the most essential reason for carrying out the examination or program for treatment. In the case of a traffic accident, the ER registration also includes information on crash characteristics (e.g., transport modes involved, number of vehicles involved, crash location) and personal information on the patient (e.g. age, gender, civil registration number). An important difference from the data collected by the police is that the road user information is not linked to the crash but the crash is linked to the road user.

A lot of information is gathered in the LPR data but, unfortunately, these data suffer a lot from under-reporting due to mistakes or lack of time from the staff at the ERs. This means that traffic accidents are sometimes registered as something else (e.g. accident happened at home, garden accident, tripping accident) and even important information as location of ER is missing.

At the Odense University Hospital a special team, the Accident Analysis Unit, has specialized in accident data and their job among other is to validate and quality check the data. This unit verifies that data are collected and collected correct, with respect to contact cause, accident type and road crash information. The unit handles and works with all data gathered by the three ERs located at Funen (e.g. Odense, Svendborg and Middelfart).

The ER at Odense University Hospital has extra equipment to collect data available and this guaranties more accurate data. For example, the exact location of the incident can be plotted on a screen, located at the entrance of the ER. After end injury reporting the accident report is checked carefully for mistakes by a member of the Accident Analysis Unit. If anything does not match in the report, the nurses or doctors who followed the patient are asked some in-depth questions and the report is afterward corrected.

2.3 COMBINING THE POLICE AND ER DATA

The two sources of accident data were added to the server of Statistics Denmark and a pseudo-civil registration number were given each person in the dataset. Thereby, it was possible to match the two data sources and get access to some more data with socio-economic characteristics of each person involved in a traffic accident.

2.3.1 Matching of data sources

Both databases are considered as complete and accurate since both undergo comprehensive consistency checks by several authorities. Due to the validation processes, the difference in the number of fatalities between police and hospital records is likely administrative. The differences in the fatalities are mainly due to the screening practice of presumed suicides and sudden deaths from police records, as well as missing registration of morgue admissions.

Preparation of the two data sets is conducted in the software SAS. Previous studies (e.g., Meuleners et al., 2006; Amoros et al., 2006; Lateef, 2010; Thomas et al., 2012) matched police and hospital records on the basis of matching characteristics (e.g. date, gender, age) in the absence of an individual civil registration number. This may lead to

the false positive identification of matching records when the matched records are highly similar but do not derive from the same crash. For this study, an individual pseudo-civil registration number is used. This guaranties a more accurately matching, without risk of false positive identification of similar crashes as the same crash.

After combining the two sources, a total of 34,921 road users involved in a road crash was found for the period 2002-2008, out of these 15,745 reported to the police and 25,283 reported to ERs. Of these road users, 6,107 (17.5%) reported both to the police and the ER. These data were linked together and linked to some individual characteristics available at the Statistics of Denmark.

2.3.2 Data cleaning

In this study, a 6-year time period is used, namely 2002 to 2008. Due to a long time frame, renaming of some of the variables in the two data sets was found, but mostly within the police registered data. For some variables, the content was even changed either in the form of including or excluding more subjects or geographic areas. The biggest change in the police registered data was in 2003, where a reform within the police was conducted and thereby size of regions and municipalities changed. Therefore, the data from 2002 are only used in the study where the area condition was unimportant. The plan was, in the beginning, to use many variables from Statistics Denmark, but also here some problems with the renaming of variables and the content of variables appeared, hence only three variables were used in the end.

In the police registered data a lot of variables had changed names in the study period (e.g. transport mode, seatbelt, helmet, injury type, gender). Therefore, a lot of data preparation was necessary before any modelling could be made. Before analysis of the data was made, it was also necessary to make new variables either by grouping some of the existing subjects within a variable or even make groups within a variable. For example was "*transport mode*" merged into nine sub-subjects instead of the current sixty-seven subjects (e.g. pedestrian, cyclists, moped, motorcyclists, car, van, bus, truck) while "*age*" was divided into ten different age groups. Furthermore, some new variables for day and time of the accident were made (e.g. weekend, weekday, peak-hour, daytime, afternoon, evening, night). From the Statistics Denmark variables as income, civil status and last finalized education are used, but also here it was necessary to make a lot a work on renaming and group merging of the subjects within each variable.

For a part of the analysis conducted in this thesis, it was necessary to use variables from two different sources as one variable, for example "*injury degree*". For that reason, it was necessary to decide which source the value in the variable should be valid from. It must be expected that the police, which are present at the crash scene, have more accurate information about crash characteristics than the ER. Therefore, values from different crash characteristic variables were taken from the police registered data whenever possible. Likewise, it must be expected that the ER have more precise

information about the injury degree and therefore "*injury degree*" is used from the ER data.

The AIS code given in the ER data is used as an injury score and is transformed into a 4-step injury scale to mimic the police scale. It includes the ER injury severity score (ISS), namely the sum of squared AIS, in the analysis: ISS 1 was assigned to "*no (or minor) injury*", ISS 2 to 4 were assigned to "*slight injury*", and ISS over 5 was assigned to "*severe injury*".

For one study in the thesis, an action diagnostic code was used and transformed into six categories. Each code within the variable "*action diagnostic*" consists of a letter followed by a number (i.e. S009). The "*S*" or "*T*" in each code stands for a diagnostic with an injury where "*S*" is given with a number from 0 to 9 and "*T*" is given with the numbers 20, 89, 109 and 129. These numbers describe where on the body injuries are found. From these codes, the variable "*trauma type*" was made and divided into five different groups (e.g. head and neck, thorax, upper extremity, lower extremity and spine. Undefined codes within the variable "*action diagnostic*" and codes for, *only an examination of the patient,* were gathered in a category "*other injuries*".

2.4 LARGE-SCALE SURVEY AMONG YOUNG CYCLIST

The first large-scale survey conducted in this thesis investigates the barriers and motivation for cyclists in Denmark to self-report bicycle crashes to the police or hospital.

2.4.1 Survey design

Data were collected via a custom-designed web-based questionnaire which was carefully designed on the basis of literature about incident reporting. The survey was designed according to the Theory of Planned Behaviour (TPB) (Ajzen, 1991) and concerns the individual's intention to perform a specific behaviour namely to report traffic incidents to the police or hospital. The questionnaire was divided into five parts.

First, the survey elicited the respondents' cycling habits in terms of how often they use cycle, average distance, cycling experience and accident experience. Second, some questions about the last cycling incident in terms of time-of-day, distance from nearest hospital and nearest police station, distance from the residence, health symptoms experienced, accompanying persons and collision partners. Third, the reporting intentions of future cycling incidents were asked. The respondents were asked about both the willingness to report a future cycling incident provided that the reporting method may be selected (i.e., police, hospital, internet, mobile app) and that the information is used for improving cycling safety. Fourth, some questions about the individual attitudes, subjective norms, and perceived behavioural control which were measured on a 5-point Likert scale ranging from "strongly disagree" to "strongly agree". Fifth, the elicited cyclists' where at last asked some socio-economic characteristics including age, gender, income, place of residence, relationship status and having children.

2.4.2 Survey administration

The survey was administered in Danish via three types of on-line cyclists' social networks during September and October 2014. The first type consists of formal social networks for promoting cycling: the network of Odense - the city of cyclists, and the network of the Danish Cyclist Federation. The second type consists of academic social networks in several universities all over the country since students form an important part of the cyclist population in Denmark. In fact students cycle 2.7 km each day where employees only cycle 2.0 km each day (TU Cycling, 2014). The different academic networks were: Technical University of Denmark, University of Copenhagen, Aalborg University, Soenderborg Gymnasium, and Roskilde University. The third type includes the professional and personal networks of transport stakeholders with an interest in cycling research: Danish Road Directorate, Danish National Police, insurance companies, municipalities, and the Danish Council for Traffic Safety. The survey administration through the third type of social networks was promoted by an official newsletter followed by personal correspondence.

2.5 LARGE-SCALE SURVEY AMONG TRANSPORT PRACTITIONERS

The second survey in the Ph.D. study was made to understand the possibilities of improving the handling of traffic accidents by using a service management perspective. The survey was administrated among decision makers in the transport field.

2.5.1 Survey design

The framework of the survey is motivated by Mastrofski's Six Domains of Performance (Mastrofski, 1999) which are based on the SERVQUAL framework (Parasuraman et al., 1985). From an evaluation of previous studies made to investigate service quality within the police, this study postulates that the following five dimensions have an impact on the service quality within the police for handling traffic accident reporting.

Accessibility: Ease of contact to the police when reporting a traffic accident, including distance to the police station and waiting time.

Tangibles: Equipment in the waiting rooms and technology available for the police officers to handle traffic accident reporting.

Responsiveness: *Responsiveness*, *competence* and *reliability* of the police officers in terms of fast service, resolving problems in traffic accidents effectively, and dedication of time to citizens.

Caring: Understanding the citizens and making the citizens feel safe when reporting traffic accidents.

Fairness: Sense of justice (or *fairness*) from the police officers in terms of handling the reporting of traffic accidents in a fair and neutral way.

The questionnaire was divided into six parts. First, the survey elicited some socio-economic characteristics as age, gender and workplace location followed up by some

questions about their knowledge of different safety subjects (e.g. accident report, traffic safety planning, black spot analysis, safety campaigns). Second, some questions about previous traffic accident experience and visits' to the police station and hospital as a private person. Third, the respondents thought of the importance of accident reporting to police or hospital together with a rating of the five dimensions importance for the handling of traffic accidents reporting within the police and hospital. Fourth, the respondents were asked to state their confidence level for answering questions about the police. Afterwards, the respondents were asked to rate the importance for each question within the five dimensions for the handling of accident reporting within the police. Fifth, the respondents were asked to state their confidence level for answering questions about the hospital. A follow up by an importance rating was required for each question in the five dimensions with respect to the handling of accident reporting within the hospital. Sixth, some questions about possible improvements within the police or hospital on the handling of accident reporting together with the respondents thought of possible improvement in accident reporting. All rating questions were given on a 5-point Likert scale which went from "no importance" to "very important".

2.5.2 Survey administration

The questionnaire was administrated among different decision makers (e.g. authorities, researchers, NGO, consultants, transport suppliers). The pre-test of the questionnaire were administrated at a National transport conference (Trafikdage at Aalborg University 2015) and ended up with 20 completed answers. Due to the very low completion rate (39%) and comments from respondents the survey were drastically changed and shorten. The new questionnaire was distributed to different consultancy companies (e.g. Cowi, Trafitec), transport suppliers (e.g. DSB, Banedanmark), authorities (e.g. The Danish Road Directorate, Municipalities, police agencies), NGO's (e.g. Counsel for Safe traffic, Danish Cyclist's Federation) and universities (e.g. DTU Transport, Aalborg university). Due to a very high uncertainty level given by the respondents for answering questions about the hospital, the hospital part was taken out of the analysis.

3 THEORY AND METHODS

To understand the extent of under-reporting, the behavioural reasons and the possibilities for improving the reporting rate, some mathematical and statistical analyses were used: (i) the extent of under-reporting was estimated with statistical calculations where the comparison of two reporting databases was conducted; (ii) for the in-depth investigation of the differences in the two data sources some discrete choice models were used; (iii) to understand the motivation and barriers for incident reporting the attitudinal survey was analysed by means of structural equation models; (iv) for the exploration of how to improve the reporting rate of traffic accidents a SERVQUAL, MCDA and LCA approach was used. The conducted analyses are described in the following subsections.

3.1 CAPTURE-RECAPTURE

Under-reporting rates are estimated with the capture-recapture method commonly used in ecology to estimate animal population size and in epidemiology to estimate disease spread. The method estimates the share of overlapping records in two independent samples (see Figure 3.1.1) while assuming that (i) the population is finite and closed, (ii) common records are unambiguously identified, (iii) records are independent, and (iv) records are homogeneously catchable.

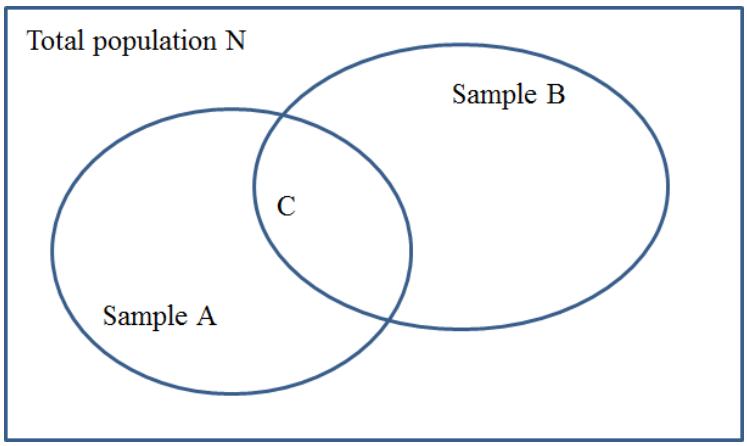

Figure 3.1.1: The capture-recapture method

The capture-recapture method can be applied by different estimators and among these are the Lincoln–Petersen estimator and its modified version, the Chapman estimator, Chao's lower bound estimator, the Zelterman's estimator, McKendrick's moment estimator and the maximum likelihood estimator. For the purpose of estimating the total number of road users involved in a traffic accident the nearly unbiased estimator (Wittes, 1972) is used by applying the Chapman capture-recapture formulary:

$$N = \frac{(a+1)(b+1)}{(C+1)} - 1 \tag{3.1.1}$$

N is then the total number of the population, a is the total number of observations in sample A, b is the total number of observations in sample B, and C is the number of observation registered in both samples A and B. The variance and 95% confidence interval (CI) for the estimate of N is calculated as follows:

$$Var(N) = \frac{(a+1)(b+1)(a-C)(b-C)}{(C+1)^2(C+2)} \tag{3.1.2}$$

$$95\%\, CI(N) = N \pm 1.96\sqrt{Var(N)} \tag{3.1.3}$$

3.2 Discrete choice models

Discrete choice models are mainly made to describe, explain and predict decision makers' (e.g. people, firms, households) choice among two or several discrete alternatives such as the choice between different transport modes. Discrete choice models are usually derived from the principle of utility maximization (Ben-Akiva & Lerman, 1985), which implies that the alternative with the highest utility is selected. The most famous types of discrete choice models are logit, generalized extreme value, probit, and mixed logit. The different models are derived under different specifications of the density of unobserved factors. For that reason, the model specification derives from what distribution assumptions are made for each model and what motivates the different assumptions. Below are the theory behind the two types of discrete choice models, logit and mixed logit, used in this thesis described.

Binary logit is a logit model where variables can vary over alternatives based on binary data. The logit model is far the most used and easiest among the different discrete choice models. The popularity is mainly due to the easy interpretation and its closed form. McFadden (1974) completed the analysis of the logit model by showing that the logit formulary for the choice probabilities essentially implies that unobserved utility is distributed extreme value.

The utility function U_{ni}^M for observation n recorded in database M to have a match i with another database T is expressed as follows:

$$U_{ni}^M = V_{ni}^M + \varepsilon_{ni}^M = \beta_M X_{ni}^M + \varepsilon_{ni}^M \tag{3.2.1}$$

where V_{ni}^M is the deterministic part of the utility function, X_{ni}^M is a vector of observable variables in the M database, β_M is a vector of parameters to be estimated, and ε_{ni}^M is a

vector of i.i.d. Gumbel error terms. The probabilities of observing a match *i* for observation *n* in database *M* and T are expressed as:

$$P_{ni}^{M} = \frac{\exp\left(V_{ni}^{M}\right)}{\exp\left(V_{ni}^{M}\right)+\exp\left(V_{ni}^{T}\right)} = \frac{\exp\left(\beta_{M} X_{ni}^{M}\right)}{\exp\left(\beta_{M} X_{ni}^{M}\right)+\exp\left(\beta_{T} X_{ni}^{T}\right)} \tag{3.2.2}$$

$$P_{ni}^{T} = \frac{\exp\left(V_{ni}^{T}\right)}{\exp\left(V_{ni}^{M}\right)+\exp\left(V_{ni}^{T}\right)} = \frac{\exp\left(\beta_{T} X_{ni}^{T}\right)}{\exp\left(\beta_{M} X_{ni}^{M}\right)+\exp\left(\beta_{T} X_{ni}^{T}\right)} \tag{3.2.3}$$

Estimates of the vectors β_M and β_T provides insights into the different determinants in the databases (Train, 2009).

Mixed logit is a very flexible discrete choice model which can approximate any random utility model (McFadden & Train, 2000). The model is able to handle the three limitations in standard logit, namely random taste variation, unrestricted substitution patterns, and correlation in unobserved factors. Another advance is that the mixed logit model is not restricted by a normal distribution. Mixed logit models have been known for many years but not until the development of simulation the model has become fully practicable. The first application of a mixed logit model integrated in 1980 jointly by Boyd & Mellman (1980) and Cardell & Dunbar (1980). The improvement of computer speed and the understanding of simulation methods have caused that mixed logit models have reached their true potential (Erdem, 1996; Brownstone & Train, 1999).

The mixed logit models are defined on the basis of the functional form for its choice probability. Conditional on values for the alternative specific constants α_i and the error components μ_h the logit probability for decision maker *n* to choose alternative *i* is formulated according to the well-known multinomial logit model:

$$P_{in} = \frac{\exp\left(\alpha_i + \sum_{k=1}^{K} \beta_k X_{ikn} + \sum_{h=1}^{H} \mu_h d_{ih}\right)}{\sum_{j=1}^{J} \exp(\alpha_j + \sum_{k=1}^{K} \beta_k X_{jkn} + \sum_{h=1}^{H} \mu_h d_{jh}} \tag{3.2.4}$$

β_{ik} are parameters of *K* variable attributes to be estimated for each alternative *i*, μ_h are error component parameters to be estimated for representing cross-nested similarities across alternatives, X_{ikn} are values of *K* associated to each alternative *i* for decision maker *n*, and d_{ih} are indicators of *H* nests that are equal to 1 if alternative *i* belongs to nest *h* and zero otherwise. The error terms ε_{in} are independently and identically distributed Gumbel.

Alternative specific constants are formulated as $\alpha_i \sim N(\mu_i, \sigma_i^2)$, where μ_i is the mean and σ_i^2 is the variance of the normal distribution of each constant. Accordingly, the probability of decision maker *n* choose alternative *i* may be integrated over the distributions $f(\alpha_i)$ and $f(\mu_h)$ of the random parameters:

$$P_{in} = \int \left[\frac{\exp\left(\alpha_i + \sum_{k=1}^{K} \beta_k X_{ikn} + \sum_{h=1}^{H} \mu_h d_{ih}\right)}{\sum_{j=1}^{J} \exp(\alpha_j + \sum_{k=1}^{K} \beta_k X_{jkn} + \sum_{h=1}^{H} \mu_h d_{jh}} \right] f(\alpha_i)\, f(\mu_h)\, d\alpha_i d\mu_h \qquad (3.2.5)$$

The probability does not have a closed-form expression because of the multi-dimensional integral, and hence the maximization of the likelihood function for parameter estimation requires simulation that consists in maximizing the following expression:

$$SLL = \sum_{n=1}^{N} \sum_{i=1}^{I} d_{ni} \left\{ \frac{1}{R} \sum_{r=1}^{R} \left[\frac{\exp\left(\alpha_i^r + \sum_{k=1}^{K} \beta_k X_{ikn} + \sum_{h=1}^{H} \mu_h^r d_{ih}\right)}{\sum_{j=1}^{J} \exp(\alpha_j^r + \sum_{k=1}^{K} \beta_k X_{jkn} + \sum_{h=1}^{H} \mu_h^r d_{jh}} \right] \right\} \qquad (3.2.6)$$

where *SLL* is the simulated log-likelihood, *N* is the number of decision makers, d_{ni} is equal to 1 if decision maker n choose alternative *i* and 0 otherwise, *r* is one of the *R* random draws required for integral simulation, and the superscript *r* represents the instance of a draw of the constants α_i and the error components μ_h.

3.3 Theory of Planned Behaviour

The human behaviour is a complex and difficult task to predict, nevertheless are the TPB construct (Ajzen, 1991) a method which can be used for that purpose. The TPB is based on the theory of reasoned action (Ajzen & Fishbein, 1980; Fishbein & Ajzen, 1975) and as a central factor for both theories is the intention to perform a given behaviour. The TPB states that three factors explain the intention for performing a behaviour which is the *attitudes towards the behaviour*, the *subjective norm* and the *perceived behavioural control*. Here, the attitude refers to the person's evaluation of favourable and unfavourable sides of the behaviour, the subjective norms are the influence from family and friends and their opinion on the behaviour, and the perceived behavioural control refers to the ease or difficulties by performing the behaviour. Depending on how strong an intention for performing the behaviour is the actual behaviour will or will not be performed.

3.4 Structural Equation Models

Structural equation models (SEM) are mainly used to investigate a hypothesized behavioural framework by assessing the unobserved latent construct. SEM is often used in social science because of the possibility to assign the latent construct with the observed variables. The method was developed back in the 1960s and 1970s, together with the computer evolution. The development of the method was conducted in three separate stages and mainly at the Cowles Commission and the University of Uppsala. For this thesis, the model contains three sets of equations: measurement equations (eq. 3.4.1), structural equations linking the latent attitudinal constructs (eq. 3.4.2), and structural equations relating the latent attitudinal constructs (eq. 3.4.3).

$$I_{dn} = Z^*_{ln}\alpha_d + \upsilon_{dn} \quad and \quad \upsilon_n \sim N(0, \Sigma_\upsilon) \quad for\ d = 1,...,D \tag{3.4.1}$$

$$Z^*_{ln} = SC_{ln}\beta_{lm} + \omega_{ln} \quad and \quad \omega_n \sim N(0, \Sigma_\omega) \quad for\ l = 1,...,L \tag{3.4.2}$$

$$R^*_{in} = Z^*_{ln}\beta_r + \xi_{in} \quad and \quad \xi_n \sim N(0, \Sigma_\xi) \quad for\ i = 1,...,I \tag{3.4.3}$$

where Z^*_{ln} is the value of latent construct l for observation n, I_{dn} is the value of an indicator d of the latent construct Z^*_{ln} as perceived by observation n, SC_{ln} is a vector of different observation characteristics, and R_{in} is a vector of the intentions to perform a given behaviour. Error terms are expressed as elements υ_{dn}, ω_{ln}, and ξ_{in} of the vectors following a normal distribution with respective covariance matrices Σ_ω, Σ_υ and Σ_ξ, while parameters to be estimated are α_d, β_{lm}, and β_r. Considering D indicators translates into writing D measurement equations and estimating a ($D\times1$) vector α of parameters (i.e., one parameter is estimated for each equation), while considering L latent constructs translates into writing L structural equations and estimating an ($M\times L$) matrix of β parameters (i.e., M parameters are estimated for each equation).

3.5 SERVQUAL

The SERVQUAL framework (Parasuraman et al., 1985) is performed to measure service quality in the private sector. From focus group interviews the study of Parasuraman et al. (1985) found 10 possible dimensions to be important factors to evaluate service quality. The 10 dimensions are: 1) Reliability which involves dependability and consistency of performance; 2) Responsiveness which imply fast and willing service; 3) Competence in form of skills and knowledge on the service which are provided; 4) Accessibility includes ease of access as minimal waiting time; 5) Courtesy in terms of polite and friendly contact staff; 6) Communication which involves good information to the customers; 7) Credibility in form of honesty and trustworthiness; 8) Security could be physical and maybe also financial safety; 9)Understanding of the costumers need; 10) tangibles includes the physical facilities but also available equipment to provide the service. A broad array of studies have been made on the field and a lot of suggestions on a more compacted framework with only five or six dimensions have been proposed (Zeithaml et al., 1990; Mastrofski, 1999). The method has previously been used to evaluate service quality for public service, product system service, banks and police agencies (Brysland & Curry, 2001; Donelly et al., 2006; Kumar et al., 2009; Catulli, 2012).

3.6 MULTI-CRITERIA DECISION ANALYSIS

MCDA is a sub-discipline of operations research which explicitly considers multiple criteria in decision-making often used among an expert panel. The method is based on the decomposition approach, namely the divide-and-conquer (DAC) principles (dividing the large and often complex problem into smaller units that can be dealt with more easily). The SMART (Simple Multi-Attribute Rating Technique) approach is an MCDA method which are developed by Von Winterfeldt and Edwards (1986). SMART allows the evaluation of a finite number of decision alternatives with respect to a finite number of performance criteria. The SMART approach consists of four consecutive

steps. The first step consists of identifying strengths, opportunities and threats associated with for example new technology. The second and the third steps concern the rating of the things connected to strengths, opportunities and threats in terms of the relative importance. For the second step, namely evaluating the impact (score) of the strengths, opportunities and threats, the SMART technique is applied. The things which are associated with strengths, opportunities and threats are ranked in a subjective order of preference and rate the overall impact. In the technique, ratings (scores) are assigned directly in the natural scales of the attributes. In the third step, the SMART technique is applied for eliciting criteria weights by using a visually supported scale. The last step is a reflecting procedure where the experts are requested to state the improvement possibilities for example for new technology.

The MCDA are often used as a tool to solve complex problems and have been used for many purposes for example testing of interest in new technology (Kaplan et al., 2015) measure service quality (Oddershede et al., 2014) or selection of projects (Barfod, 2012).

3.7 LATENT CLASS ANALYSIS

Latent class clustering was conceived more than four decades ago, but not until the last decade there was a renewed interest on the application. Advances in computational capabilities led to a wide-spread application in a diversity of social science studies (see, e.g., Vermunt & Magidson, 2002; Lanza et al., 2007). Since the number of clusters and their form is unknown the method can be considered as an unsupervised learning approach (e.g., Magidson & Vermunt, 2002; Depaire, 2008). The main advantages of Latent Class Analysis (LCA) over alternative and traditional clustering approach (e.g., k-means clustering, hierarchical clustering, co-clustering) are the ability to represent overlap across clusters rather than only independent or nested clusters, the existence of an underlying statistical model that allows calculating cluster probabilities for new cases, and the provision of several goodness-of-fit criteria that facilitate the decision regarding the number of clusters (see, e.g., Magidson & Vermunt, 2002; Depaire et al., 2008).

LCA is defined as the classification of similar objects into C latent classes, where their sizes are unknown and uncertainty is involved in the class membership and the number of clusters. Assume that N observations form a vector which is characterized by another vector of M variables $(y_i = y_1,\ldots,y_M)$, and let $(Y_i=Y_{i1},\ldots,Y_{iM})$ be the vector of values of observation i for the M items. Then, the latent class model is as follows (see, e.g., Depaire et al., 2008):

$$p(Y_i \mid \theta) = \sum_{k=1}^{K} P(C_k)\, p(Y_i \mid C_k, \theta_k) \tag{3.7.1}$$

where $(k=1,\ldots,K)$ indicate a latent class, K the number of latent classes, $P(C_k)$ denotes the prevalence of latent class C_k, θ_k is a vector of unknown parameters to be estimated, and $p(Y_i \mid C_k,\theta_k)$ denotes the conditional multivariate probability that an observation in class C_k would be characterized by Y_i. To reach a model with reasonable parametric

complexity to estimate, four assumptions have to be made: (i) Every variable *i* in the model is assumed to be an ordinal indicator with R_m possible responses (r_{mi} =1,…,R_{mi}); (ii) Observations are assumed to be uncorrelated. (iii) Categorical indicators are assumed to be independent within a latent class. (vi) Categorical indicators are assumed to be endogenous indicators of the latent class. Under these conditions, the LCA model can be formulated by the following (Lanza et al., 2007):

$$p(Y_i \mid \theta) = \sum_{k=1}^{K} \pi_k \prod_{m=1}^{M} \prod_{r_m=1}^{R_m} \theta_{mr_m|k}^{I(y_{im}=r_m)} \tag{3.7.2}$$

where *k* is the latent class which observation *i* is member of, *I* is an indicator function that equals 1 if y_{im} equals r_m and 0 otherwise, π_k and θ_{mr_m} are parameters to be estimated. The parameters π_k represent class membership probabilities and θ_{mr_m} are indicator response probabilities conditional on the latent class membership.

4 PH.D. PROJECT

The aim of this Ph.D. project was to build state-of-the-art structural statistical prediction models for the number of road crashes and thereby get closer to build a more accurate prediction model. This motivated to an investigation on how reliable the National Crash databases in Denmark are, in which extent the under-reporting of road crashes are, what are the reasons underlying the under-reporting, and what can be done to improve the reporting rate.

To explore these questions, four studies were conducted which ended up in a total of four papers. The first paper investigated the extent of under-reporting in traffic crash data collected by the police which is the official road crash database in Denmark and is used as National Crash database. The second study unravelled the relationship between registration of road crashes to the police and the hospitals. The first and the second study motivated to make the third study, where the reasons underlying the under-reporting problem for cyclists were investigated by using Theory of Planned Behaviour as framework. The findings for the third study made it reasonable to conduct an investigation of stakeholders' opinion of the service quality for the handling of traffic crash reporting and thereby reveal which factors that should be improved in order to benefit the reporting rate the most.

4.1 PAPER 1

Understanding traffic crash under-reporting: Linking police and medical records to individual and crash characteristics.

Accepted in Traffic Injury Prevention

4.1.1 Description

The current study investigates the likelihood of reporting road crashes to the hospital and the police as a function of individual characteristics, trauma type, severity degree and crash characteristics. The data used in this study covers all road crash injuries that occurred in the province of Funen (Denmark) between 2003 and 2007 and were registered to the police, the hospital, or both authorities.

A capture-recapture model is used to explore in which degree the under-reporting of traffic crashes appear in Denmark. The capture-recapture procedure does not address the problem of heterogeneity in the two data sets, therefore, two jointly binary logit models are estimated which allows capture of the heterogeneity in reporting to the police given a report to the hospital has been made, and vice versa.

Model estimation providing insights into the actual reasons for road crashes appearing in the hospital and/or police records and understanding the heterogeneity in the reporting of a road crash in the two databases is essential for devising policy measures

aiming at increasing the reporting rate by targeting specific road user groups or specific situational factors.

4.1.2 Findings

This study adds significantly to the literature about under-reporting by recognizing that the heterogeneity in the reporting rate of a traffic crash which may lead to devising policy measures. This implies that policy measures aiming at increasing the reporting rate by targeting specific road user groups (e.g., males, young road users) or specific situational factors (e.g., light injuries, arm injuries, leg injuries, weekend) may lead to wrong adjustments.

This study computes the total number of road users involved in road crashes with the capture-recapture method and then estimate the likelihood that a road user involved in a road crash and reported to the hospital will report also to the police, and vice versa. Expectedly, the total number of road users involved in a road crash in Funen in the study period turned out to be much higher than the number found in police records only. Even the number of fatalities turned out to be different in the two data sources.

Notably, the reporting rate to the police is a bit lower than the rates found in other studies (see, e.g., Aptel et al., 1999; Amoros et al., 2007) conducted in other Countries, possibly because the police in Denmark only are obligated to report the crash if the police officers at the scene evaluate that the road crash as serious enough or if the road user wants to use the report for an insurance claim.

Estimates of the two binary models, revealed lower reporting among males and older road users, possibly because females in general are more aware of their own health, while children always are passengers that need help to get out of the vehicle and be taken to a health check at the hospital after their involvement in a road crash. Seatbelt and helmet use were found related to a higher probability of reporting to both authorities, possibly because their use indicates higher awareness from the road user. A higher number of parties involved were found associated with a higher likelihood of reporting to both authorities. Similarly, crashes on roads with higher speed limits are more “visible” and hence relate to an increase in the likelihood of reporting.

Lastly, model estimates confirmed that the injury severity is related to the probability of reporting to the police and the hospital. Often the police arrives first to the crash site and call for an ambulance thus deciding which road users will report to the hospital. Model estimates showed that road users with head, thorax, and spine injuries are more likely to appear in both databases, most likely because the police have sent these road users to the hospital while the ones with arm or leg injuries appear less severe and less urgent to treat.

The scale factors revealed that the police dataset contains more noise than the hospital dataset, and in general the loss of information in the police records confirms that road safety analysis relying on police data might be biased (e.g., Farmer, 2003; Abay, 2015).

4.2 PAPER 2

Unravelling the relationship between trauma types and traffic crash characteristics: an error component logit approach.

Accepted and presented at the TRA conference 2014

4.2.1 Description

This study focuses on modelling the probability of a wide range of injury types with crash, vehicle and persons' characteristics, with a separate analysis for car occupants and VRUs. The considered injury types are combinations of primary and secondary injuries occurring in the following body parts: head, neck, thorax, spine, upper extremities, lower extremities and other. The employed model is the mixed-logit model due to its ability to accommodate a cross-nested error structure for representing correlations across combinations of injury types, as well as heteroscedasticity.

Data for the analysis are retrieved from police and emergency rooms on the island Funen in Denmark during the years 2002 to 2008. The Danish Bureau of Statistic links the two data sets via pseudo civil registration numbers as unique identifiers.

4.2.2 Findings

Results shows that injury types is related to the use of safety gear (such as seat belts and helmets), the configuration of the crash, the characteristics of the environment and the light conditions, and to characteristics of the road users such as gender and age. In particular, results highlight that injuries to head-neck, spine and thorax relate to the crash and individual characteristics, an interesting finding when considering that these are the body parts with the potentially most severe consequences when injured.

On-site decisions regarding the identification of critical injuries have an important role in the survival rate of people injured in road crashes. For that reason results shows great importance when considering that the decision making on crash sites relates nowadays to guidelines and protocols based on experience. Findings from this study suggest how to develop a DSS system that could be complementary to the guidelines currently in operation today. For example, the findings suggest correlation of specific injury types with specific crash configurations, and could suggest which type of intervention prioritize if a priority scale of body parts is considered. Moreover, findings from this study suggest how safety gear is very helpful to prevent critical injury types, thus have extensive potential in reducing the most severe consequences by reducing injuries to head-neck, spine and thorax.

4.3 PAPER 3

The choice to report cycling crashes to the police and hospitals in Denmark: the role of attitudes, norms and perceived difficulties.

Submitted to Transportation Research Part F: Traffic Psychology and Behaviour

4.3.1 Description

The current study explores the factors associated with the intentions to report an accident to the police and/or hospital, with a particular focus on cyclists in Denmark. The behavioural framework proposed for the analysis in this study is Ajzen's (1991) Theory of Planned Behaviour (TPB), which has been adapted to the research context of under-reporting of cycling accidents. Since there is currently no information regarding the underlying reasons for the under-reporting of traffic accidents in general, and cycling accidents in particular, the proposed behavioural framework is based on the under-reporting of other types of incidents involving personal harm and material damage from other sectors.

The hypothesis of the framework is that cyclists' intentions to report a cycling accident/incident to the police and/or the hospital are related to their attitudes towards reporting usefulness and efficiency in terms of time management, the opinions of family and friends that shape the social norms towards reporting, and the perceived difficulties including distrust in the police and medical consultation aversion.

A custom-designed web-based questionnaire was developed for data collection and Structural Equation Models (SEM) were employed for modelling the cyclists' intention to report a cycling accident in the future according to the proposed behavioural framework.

4.3.2 Findings

The findings confirm the hypothesis that not only the reporting intentions, but also the attitudes towards cycling accident reporting, are directly related to the perceived difficulties to report. Applying the novel TPB approach, which relates the attitudes to the perceived difficulties, implies that the difficulties associated with the accident reporting need to be resolved in combination or prior to awareness campaigns about accident reporting. This result has an implication also on incident reporting in general, as assuming the traditional TPB approach without testing for the existence of cognitive dissonance could generate suboptimal and biased solutions, leading to ineffective policy solutions. The following three main results are found according to the novel TPB approach:

1) Attitudes that accident reporting is useless is the most relevant factor related to the lack of intention to report future accidents. The perceived uselessness of accident reporting is in contradiction to its factual usefulness for improving traffic safety. The reason is that the perceived uselessness of reporting is directly related to the subjective norms and perceived difficulties in reporting, rather than the factual knowledge regarding the societal benefits of reporting. In fact, respondents exhibited in the survey a general lack of knowledge regarding the societal importance of accident reporting and the use of accident reports for research aiming at improving traffic safety. Therefore, campaigns should address the societal usefulness of accident reporting with the aim of increasing road incident reporting, and more specifically awareness

campaigns could serve as a tool to increase the knowledge regarding the factual usefulness of accident reporting.

2) Concerns about family distress and social image are the second most important factor associated with both non-reporting intentions and the preference to allocate time to other activities. Policy measures should aim at generating a wider acceptance of the occurrence of accidents and emphasizing the importance of allocating time to reporting.

3) The perceived difficulties to report to the authorities (mainly medical consultation aversion) and concerns regarding social distress are positively correlated with both non-reporting intentions and the preference to allocate time to other activities. Most of the cycling incidents occur close to the residence place, likely discouraging or postponing accident reporting, and two possible courses of action might resolve this situation. The first course of action is related to enhancing the speed and privacy of accident reporting as well as allowing the possibility to report without direct communication with the authorities. In fact, the respondents indicated that a mobile app or an internet website would facilitate the reporting process. The second course of action is related to enhancing the service quality management of the reporting bureaucracy, given that under-reporting of cycling accidents is associated with the attitudes and difficulties related to the accident reporting bureaucracy.

4.4 PAPER 4

Stakeholders' perspective on improving traffic crash reporting: a combined MCDA and LCA approach.

Submitted to Journal of Service Research

4.4.1 Description

The current study extends the body of knowledge by focusing on the police service quality in handling traffic crash reporting. The importance of this issue stems from the need to increase the extent and the quality of traffic crash reporting, and from the large share of traffic accident reporting in people' incident reporting to the police (Maguire & Johnson, 2010). The study offer a new expert-based decision support tool that enables stakeholders to evaluate the overall service quality in traffic crash reporting. The proposed approach comprises a combination of the SERVQUAL model adapted to the context of handling traffic crash reporting as its core, an expert-based multi-criteria decision analysis (MCDA), and latent class clustering (LCA) to handle stakeholders' heterogeneity. This study is to the authors' knowledge the first to apply MCDA for police service quality assessment. In traditional MCDA techniques, heterogeneity across stakeholders is captured through majority versus minority opinion or through stakeholders' socio-economic characteristics. This study is the first to consider LCA as a multi-dimensional tool for clustering stakeholders that enables to consider simultaneously opinion and socio-economic differences.

The data used for the study were collected by a web-based questionnaire built upon the SERVQUAL scale developed in the current study to elicit stakeholders' perceptions regarding the police service quality for handling traffic crash reporting. This study postulates that five dimensions (i.e. accessibility, tangibles, responsiveness, caring, and fairness) have an impact on service quality within the police when handling reporting of traffic crashes.

4.4.2 Findings

We have proposed a new approach that has successfully been applied for the purpose of eliciting stakeholder perceived importance on the handling of crash reporting within the police. The results show that, in general, there is quite a high satisfaction with the service quality in the current situation. The dimension *caring* scores the highest, mostly because the Danish society is connected with a high social trust to the police. In general, the stakeholders participating in this study view human factors (e.g. communication, interaction) as more important in order to increase the reporting rate than physical factors. Although human factors scored quite high for the current situation of the police service in handling crash reporting, the results highlight the need for further improvements.

According to the clustering results it was found that, according to stakeholders' characteristics, professional and personal experience the perceptions regarding the importance of handling traffic crash reporting are viewed differently. This means that the stakeholders' opinion on where and how much to invest in the different dimensions is not perceived the same. Nevertheless, the experts across clusters agree that *responsiveness* is the most important dimension to be improved and that it will yield higher crash reporting rates.

The proposed method to evaluate service quality demonstrates the usefulness of the tool even in countries connected with a high police service quality and opens up for possible new results for service quality evaluations.

5 FINDINGS AND DISCUSSIONS

The innovative findings in this PhD-thesis are covered by the four papers which extend the knowledge on under-reporting of traffic crashes in Denmark. This thesis contribute with brand new knowledge on the subject under-reporting and provides new methods for analysing the problem, thereby it proposes an opportunity for other countries to explore the transferability of these. In the following paragraphs the main findings and a discussion for each of the conducted papers are provided.

In the first study (paper 1) the extent of under-reporting in the police registered data was explored. Results from this study indicated a very high degree of under-reporting of traffic accidents in Denmark and not only for the less severe accidents involving vulnerable road users (e.g. pedestrian, bicyclist, moped, motorcyclist). Furthermore, in this study a low police catch rate (66-73%) for car users in severe traffic accidents were discovered. Even though the results found by the capture-recapture method under- or over-estimate the true number of traffic accidents, because of the heterogeneity problem of under-reporting, the results document the importance of solving the issue with under-reporting in order to provide reliable policy measures to improve traffic safety. The police reporting rate is a bit lower than the rates found in other studies (see, e.g., Aptel et al. 1999; Amoros et al. 2007), this is properly because the police in Denmark are not obligated to do a report unless the material damage exceeds 7,500 USD per vehicle or some persons injuries are estimated to be serious. From the scale factor in the two binary models, it was revealed that the police dataset contains more noise than the hospital dataset, which again states the importance of more accurate accident data for severity and frequency modelling. In general, the loss of information in the police records confirm that road safety analysis relying on police data might be biased (e.g., Farmer, 2003; Abay, 2015). At last, the two binary models made in the study documented the heterogeneity in data and showed the importance of socio-economic characteristics when under-reporting are explored. This means that the capture-recapture method is insufficient for documenting under-reporting since road users cannot be treated or handled as goldfish.

The second study in this thesis (paper 2) was conducted in order to investigate the systematics in the two data sources (police and hospital registered data) and to investigate how much information is gained by combining two data sources. The study shows great potential by using multiple data sources to make severity models due to the high and valuable increase in explanatory variables. For example, the detailed and accurate description trauma type found in the hospital data makes it possible to gain much more accurate information about which crash characteristics influence the severity degree for the road user. New and innovative information are gained by this study which also shows the advantages by using mixed logit models on traffic crash data. The new results found by this study provides an input for on-site decision tools regarding identification of critical injuries for emergency forces which in many cases

could make the different on whether or not it is a fatality accident or a severe accident. For example, suggest findings that the correlation of specific injury types with specific crash configurations could suggest which type of intervention should be prioritize if a priority scale of body parts is considered.

The third study (paper 3) proposed a novel and innovative behavioural framework for exploring the behavioural factors motivating the intentions to report cycling accidents, based on a non-traditional formulation of the TPB approach. This study was inspired by the results gained in study 1 and 2, about the socio-economic characteristics influence on under-reporting. Due to money limitation in the Ph.D. project, it was not possible to send the questionnaire to a selected panel where a more representative population might be found. At the same time very little information is available on the characteristics of the cyclist population in Denmark, and only the Danish National Travel survey are able to give an estimate of the population (TU, Denmark). For that reason the questionnaire sample ending up being compared with characteristics from the cyclist population extracted from the Danish National Travel survey and actually many similarities were found. The findings of this study confirm the hypothesis that not only the reporting intentions, but also the attitudes towards cycling accident reporting, are directly related to the perceived difficulties to report. This TPB approach, which incorporates the cognitive dissonance theory and relates the attitudes to the perceived difficulties, implies that the difficulties associated with accident reporting needs to be resolved. A way to solve the difficulties could be by awareness campaigns about accident reporting. Another interesting finding was connected to respondents' general lack of knowledge regarding the use of accident reports for research aiming at improving traffic safety. It was found that the attitude that accident reporting is useless is the most relevant factor related to the lack of intention to report future accidents. This again confirms the need for awareness campaigns describing why, where and how to report accidents. Concerns about family distress and social image were found as the second most important factor associated with both non-reporting intentions and the preference to allocate time to other activities. Policy measures should, therefore, aim at generating a wider acceptance of the occurrence of accidents and emphasize the importance of allocating time to accident reporting. The perceived difficulties to report to the authorities (mainly medical consultation aversion) and concerns regarding social distress were found to be positively correlated with both non-reporting intentions and the preference to allocate time to other activities. By enhancing the speed and privacy of accident reporting an increase in accident reporting might be found. The study also shows the importance of enhancing the service quality management of the reporting bureaucracy, given that under-reporting of cycling accidents is associated with the attitudes and difficulties related to the accident reporting bureaucracy.

Based on the founding in study 3 (paper 3) a new expert-based decision support tool, which enables stakeholders to evaluate the overall service quality in traffic crash reporting was made. The study (paper 4) postulates that five dimensions (i.e. *accessibility*, *tangibles*, *responsiveness*, *caring*, and *fairness*) have an impact on service quality within the police for handling traffic crash reporting and find the most relevant

dimension among these. The results show a high satisfaction with the service quality in Denmark which is in agreement with, that the Danish society is connected with a high social trust toward the police. The stakeholders participating in this study view human factors (i.e. *responsiveness, caring* and *fairness*) as more important in order to increase the reporting rate than physical factors (i.e. *accessibility* and *tangibles)*. The three dimensions *responsiveness, caring* and *fairness* generally got a high score for current situation but nevertheless some things could still be improved according to the stakeholders' opinion. From the clustering results, we found that not all stakeholders thought the best way to improve the reporting rate was by solving some problems in the human factors. Especially the cluster mostly represented by females perceived the dimensions *accessibility* and *tangibles* as a better choice to resolve in order to improve the reporting rate. This could mainly be due to the fact that it is easier to measure the number of police stations, waiting time or available electronic devices, compared to the police officers performance. These two dimensions (*accessibility* and *tangibles*) are also the dimensions which score lowest in the current situation. The results found in this study bear important policy measures. Firstly, countries with trust issues within the police could explore the Danish model more and thereby raise the reporting rate if a transferability of the Danish communication model is done. Secondly, the results highlight that improvements within human factors should be made in order to benefit the reporting rate the most in Denmark. Thirdly, the study presents an innovative method for evaluating service quality where some of the advantages are the possibility of weighting the improvement rates, the reflection procedure, and the ability to represent overlap across clusters in the clustering part.

6 CONCLUSION AND PERSPECTIVES

This Ph.D. thesis focused on the extent and reasons for under-reporting of traffic crashes together with Stakeholders' perspective on the possible solution to improving the reporting rate.

A very high under-reporting rate was found in the police registered data and some major problem with this, is that National statistics together with most severity and frequency models relies solely on these data. As illustrated, utilization of these data can lead to false conclusions due to the many biases in the police data. Furthermore, this emphasizing the many advantages of making severity models on multiple data sources.

The thesis provides new information on a connection between trauma type and crash characteristics (paper 2), and gives information which can be used to develop a DSS system that could be complementary to the guidelines currently in operation today. The results show that injury types are related to the use of safety gear such as seat belts and helmets but also to person characteristics such as gender and age. For that reason, this study illustrates that safety gear is very helpful in preventing critical injury types, thus have extensive potential in reducing the most severe consequences by reducing injuries to head-neck, spine and thorax.

A huge gap in the literature of under-reporting is the investigation of behavioural reasons for road users' choice to report or not report a traffic accident. This thesis is the first research, to our knowledge, which provides some results on this area. From the results in paper 3, it can be concluded that one of the major reasons for the low reporting rate in Denmark is that road users do not know how to report accidents or consider it important to do. The results also stimulate thoughts about policy implications for increasing accident reporting in general. Therefore, future campaigns should address the societal usefulness of accident reporting and more specifically awareness campaigns. These campaigns could serve as a tool to increase the knowledge regarding the factual usefulness of accident reporting and thereby generate positive social norms in favour of accident reporting.

Finally, this thesis presents a new method for service quality evaluation and this method was tested on the handling of traffic accident reporting within the police. Results show that an improvement of the service quality within the police might result in higher reporting rates in Denmark. Based on stakeholders' overall (average) opinion the most prominent improvement of the reporting rate can be found by resolving some of the human factors associated with reporting of traffic accidents. Therefore, more focus should be made on educating police officers in handling of traffic accident reporting. The method used for this part of the thesis demonstrates the usefulness of the tool even in countries connected with a high police service quality as in Denmark. Therefore, this result could inspire other countries to explore the transferability of the Danish communication model in handling traffic crash reporting more deeply.

The results of this project can be used in other research fields even outside transportation. Firstly, results have an implication on incident reporting in general, as assuming the traditional TPB approach without testing for the existence of cognitive dissonance which could generate suboptimal and biased solutions. Secondly, the project presents a new method for service quality evaluation for example in public transport. Some of the advantages of this new method are the possibilities of weighting the improvement rates, the reflection procedure, and the ability to represent overlap across clusters in the clustering part.

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APPENDIX

Appendix 1: Questionnaire for bicycle users

Statistisk modellering af cykeluheld

Politiet registrerer kun ca. 14% af alle cykeluheld med alvorlig tilskadekomst, mens det blot er ca. 6% med let tilskadekomst. Denne undersøgelse skal derfor forsøge at skaffe viden om, hvorfor der er så stor underrapportering af cykeluheld i Danmark og hjælpe til at finde måder hvorpå, denne underrapportering kan undgås, for derved at få bedre vilkår for cyklister i Danmark.

Dette spørgeskema er en del af et Ph.D. projekt med arbejdstitlen "Statistisk modellering af trafikuhelds hyppighed og alvorlighedsgrad" hvor rapporteringen af trafikuheld i Danmark blandt andet undersøges. Projektet er en del af et større projekt (IMPROSA) på DTU Transport og har til mål at forbedre trafiksikkerheden i Danmark.

Dine synspunkter og din besvarelse af dette spørgeskema er vigtige for os! Besvarelsen tager ca. 10 minutter. Spørgeskemaet vil være tilgængeligt frem til d. 31.10.14. Tak for din hjælp!

Som tak for hjælpen udlodder vi:
1 x 800 kr. gavekort til et restaurantbesøg
4 x 400 kr. ipod shuffles
10 x 150 kr. downloadskort til itunes
Præmien bliver trukket blandt de personer, der har udfyldt hele spørgeskemaet og givet deres navn, postnummer og emailadresse.

Spørgsmål omkring spørgeskemaet eller projektet kan skrives til Kira Janstrup på email-adressen kj@transport.dtu.dk

Statistisk modellering af cykeluheld

Dine cykel vaner

***1. Hvor ofte benytter du følgende transportmidler?**

	Sjældent	2-3 gange om måned	1 gang om ugen	2-3 gange om ugen	Hver dag
Cykel					
Bil					
Offentlig transport					

***2. Hvor mange km cykler du dagligt?**

- Mindre end 10 km
- 11-20 km
- 21-30 km
- 31-40 km
- 41-50 km
- Mere end 50 km

***3. I hvor mange år har du cyklet?**

- Mindre end 1 år
- 1-2 år
- 3-5 år
- Mere end 5 år

***4. Hvordan vil du karakterisere dig selv som en cyklist?**

- Jeg cykler kun for at træne eller motionere
- Jeg cykler kun for at komme fra et sted til et andet
- Jeg cykler både for at motionere og for at komme fra et sted til et andet

***5. Er du væltet på din cykel eller har du været involveret i et trafikuheld på din cykel inden for de sidste 10 år?**

- Ja
- Nej

Statistisk modellering af cykeluheld

Dit trafikuheld på cyklen

***6. Hvor mange gange har du været involveret i et trafikuheld på din cykel eller været væltet på din cykel inden for de sidste 10 år?**

- 1 gang
- 2 gange
- 3 gange
- 4 gange
- 5 gange eller mere

Statistisk modellering af cykeluheld

Dit sidste trafikuheld på cyklen

Tag nu udgangspunkt i dit sidste uhled.

Et cykeluheld er hvis du er:
1) væltede på cyklen på vejen eller cykelstien
2) kørt ind i en anden cyklist eller fodgænger
3) blevet kørt over af et køretøj

***7. Hvornår havde du sidst et cykeluheld?**

- Under 1 år siden
- Ca. 1-2 år siden
- Ca. 3-5 år siden
- Mere end 5 år siden

***8. Hvilke trafikanter var ellers involveret i det sidste cykeluheld? (Flere svarmuligheder)**

- Bil
- Bus
- Tunge biler
- Motorcykel
- Cykel
- Fodgænger
- Ingen

***9. Hvor langt tid på cykel fra dit hjem skete det sidste cykeluheld du havde?**

- Omkring 5 min.
- 5-10 min.
- 11-20 min.
- 21-30 min.
- Mere end 30 min.

***10. Hvor langt, tror du, der var til nærmeste sygehus / politistation fra uheldsstedet ved det sidste cykeluheld du havde?**

	0-5 km	6-20 km	21-50 km	Mere end 50 km
Sygehuset				
Politistation				

Statistisk modellering af cykeluheld

***11. Hvad tid på dagen skete det sidste cykeluheld du havde og hvordan var vejret?**

	Det var godt vejr	Det regnede	Der var sne på vejen	Det stormede
06:01-09:00				
09:01-15:00				
15:01-18:00				
18:01-20:00				
20:01-24:00				
24:01-06:00				

***12. Var der andre med dig da dit sidste cykeluheld skete? (Flere svarmuligheder)**

- Et barn i et cykelsæde/christianiacykel
- Et barn cyklende alene under 10 år
- En teenager cyklende alene over 10 år
- En voksen
- Nej, jeg var alene
- Jeg kan ikke huske det

***13. Da du sidst havde et cykeluheld oplevede du da efterfølgende dette? (Flere svarmuligheder)**

- Disorienteret, mistede synet et øjeblik, hovedpine, følsom over for lyset, ringen for ørerne
- Mistede balancen/ hukommelsen, fik kvalme
- Kastede op, talte usammenhægende, kunne ikke stå op
- Nakkesmerter, hævet nakken og havde mærker
- Kraftige ryg smerter, ømhed i ryggen
- Kraftige smerter/ hævelse i benet/ foden
- Kraftige smerter/hævelse i armen/ hånden
- Hudafskrabninger på benene/ foden
- Hudafskrabninger på armene/ hånden
- Intet af ovenstående
- Jeg kan ikke huske det

***14. Da du sidst havde et cykeluheld rapporterede du det?**

	Ja	Nej
Politiet		
Hospitalet		
Egen læge		
Akuttelefonen (1813)		
Apoteket		

Statistisk modellering af cykeluheld

Motiverende faktorer og barrierer for at rapportere et cykeluheld

De følgende spørgsmål vil hjælpe os med at forstå, hvad der er de vigtigste motivationsfaktorer og barrierer for at rapportere et cykeluheld til politiet eller hospitalet:

*15. Hvad er din mening om at et cykeluheld rapporteres / ikke rapporteres?

	Meget uenig	Uenig	Hverken enig eller uenig	Enig	Meget enig
Jeg synes, at politiet kan hjælpe i forbindelse med skyldsspørgsmål					
Jeg synes, det er min pligt at rapportere					
Jeg synes ikke, politiet plejer at skrive rapport om cykeluheld					
Jeg synes, det tager for lang tid at få fat på politiet eller hospitalet					
Jeg synes, min arbejdstid er vigtigere end at rapportere et cykeluheld					
Jeg synes, min tid kan bruges bedre på andre ting end på at rapportere et cykeluheld					
Jeg synes, det vil tage for lang tid før politiet eller ambulancen kunne komme frem til uheldsstedet					
Jeg synes alligevel ikke, at politiet vil kunne hjælpe, skaden er sket					
Jeg vil ikke rapportere, hvis jeg har drukket alkohol					
Jeg vil ikke rapportere, for jeg stoler ikke på politiet					
Jeg synes ikke, det er nødvendigt at rapportere et cykeluheld					
Jeg vil ikke forstyrre politiet eller hospitalet					
Jeg vil ikke rapportere, hvis jeg ikke synes, at jeg er kommet til skade					
Jeg vil ikke tjekkes af en læge					
Jeg synes altid, at læger er der til at hjælpe					
Jeg har haft nogle dårlige oplevelser med læger					

*16. Hvad synes dine omgivelser om at rapportere et cykeluheld?

	Meget uenig	Uenig	Hverken enig eller uenig	Enig	Meget enig
Folk jeg kender, der har haft et cykeluheld, rapporterede det					
Min familie synes, det er spild af tid at rapportere et cykeluheld					
Mine arbejdskollegaer / medstuderende synes, det er spild af tid at rapportere et cykeluheld					
Mine venner vil synes jeg er klodset, hvis de vidste jeg havde haft et cykeluheld					
Min familie vil blive urolig, hvis de vidste jeg havde haft et cykeluheld					
Mine forældre vil blive mere beskyttende, hvis de vidste jeg havde haft et cykeluheld					
Politiet / Hospitalet synes, det er unødvendigt at rapportere et cykeluheld					
Generelt plejer folk ikke at rapportere et cykeluheld					

Statistisk modellering af cykeluheld

Rapportering generelt

***17. Hvis du skulle give en vurdering, hvad er da din mening om læger og politiet generelt?**

	Meget uenig	Uenig	Hverken enig eller uenig	Enig	Meget enig
Jeg opsøger lægen, når jeg har brug for et råd. Hellere én gang for meget end én gang for lidt.					
Jeg opsøger lægen, hvis jeg tror, at jeg har behov for receptpligtig medicin eller skal vaccineres					
Jeg opsøger lægen, når jeg har lette symptomer (f.eks. feber, hoster, smerter)					
Jeg opsøger lægen, hvis jeg føler mig meget syg (f.eks. kan ikke komme ud af sengen, kraftige smerter)					
Jeg opsøger aldrig lægen					
Jeg er generelt god til at vurdere mit eget helbred					
Jeg har generelt ikke tid til at tænke på mit eget helbred					
Jeg vil helst ikke have undersøgt mit eget helbred, tænk hvis de fandt noget					
Jeg bruger generelt energi på at have et godt helbred					
Jeg bruger midler til at pleje mit eget helbred (f.eks. vitaminpiller, massage, akupunktur)					
Jeg synes, at politifolk mener de er bedre end alle os andre					
Jeg synes ikke, at politifolk er venlige					
Jeg synes, at politiet altid er glade og glædeligt hjælper					
Jeg synes, at politiet er gode til at gøre deres arbejde					
Jeg synes ikke, at politiet er effektive					
Jeg synes ikke, at politiet hjælper når man endelig har brug for dem					

Statistisk modellering af cykeluheld

Dine intentioner om rapportering af cykeluheld

***18. Vidste du at de oplysninger politiet og hospitalerne samler omkring trafikuheld inklusiv cykeluheld bruges til forskning?**

- Ja
- Jeg var ikke sikker, men jeg mente, at de blev brugt til noget vigtigt
- Nej, men det er godt at vide
- Nej, men det interesserer mig ikke

***19. Ville du rapportere et cykeluheld en anden gang, hvis du vidste, hvordan trafikuhelds data bruges til at forbedre trafiksikkerheden?**

- Ja, til syghuset
- Ja, til politistationen
- Ja, til syghuset og politistationen
- Nej, men det er godt at vide
- Nej og det interesserer mig ikke

***20. Hvis du havde et cykeluheld en anden gang, ville du da rapportere det hvis**

	Ja	Nej
Det var lovpligtigt		
Det var nødvendigt af forsikringsårsager		
Det kunne gøres via en mobil app		
Det kunne gøres nemt over internettet		
Der blev doneret 10 kr. af staten til forbedring af cykelsikkerheden		
Det kan meldes til politiet eller sygehuset (som reglerne er nu)		

Statistisk modellering af cykeluheld

Lidt om dig.....

***21. Hvad er din alder?**

***22. Hvad er dit køn?**

- Mand
- Kvinde

***23. Hvad er din sociale status?**

- Enlig uden børn
- Enlig med børn
- I et forhold uden børn
- I et forhold med børn

***24. Hvilken region bor du i?**

- Region Hovedstaden
- Region Sjælland
- Region Syddanmark
- Region Midtjylland
- Region Nordjylland

***25. Hvor bor du?**

- I byen
- I forstaden
- På landet

***26. Hvad er din uddannelse?**

- Folkeskole
- Gymnasial uddannelse
- Erhvervsuddannelse
- Kort videregående uddannelse
- Lang videregående uddannelse eller derover

***27. Hvad er din månedlige indkomst før skat?**

	kr.
Indkomst	

Appendix 2: Questionnaire for decision makers (preliminary)

Danmarks Tekniske Universitet DTU

Trafikuheldsrapportering

Underrapportering af trafikulykker er et stort problem i Danmark, hvor kun 21% af alle trafikuheld, som indrapporteres til hospitalet, også er at finde i de officielle uheldsdata indsamlet af politiet.

Din besvarelse af dette spørgeskema er vigtig for os! Vi har tillid til, at dine synspunkter, som ekspert indenfor transport området, kan skaffe viden om, hvordan man kan løse problemet med underrapportering af trafikulykker.

Vi beder dig derfor udfylde det selvom du ikke har personlig erfaring med at indrapportere et trafikuheld. I det tilfælde vil vi bede dig om at benytte dit generelle kendskab til politi- og hospitalsvæsen til besvarelsen.

Besvarelsen tager ca. 10 minutter. Som tak for hjælpen udlodder vi:

5 x 800 kr. gavekort til restaurantbesøg.

Vinderen bliver trukket blandt de personer, der har angivet deres navn og e-mailadresse.

Dette spørgeskema er en del af et Ph.d.-projekt, som er en del af et større projekt (IMPROSA) på DTU Transport og har til mål at forbedre trafiksuheldrapporteringen i Danmark.

Ved spørgsmål omkring spørgeskemaet henvises til Kira Janstrup: kj@transport.dtu.dk.

Danmarks Tekniske Universitet DTU

Trafikuheldsrapportering

* 1. Synes du, at det er vigtigt, at folk rapporterer trafikuheld til politiet og skader pådraget i trafikuheld til hospitalet?

	Vigtighed for rapportering	Vurderede mulighed for forbedringer
Politiet		
Hospitalet		

* 2. Hvordan opfatter du, vigtigheden af hvert af nedenstående emner, for at forbedre trafikuheldsrapporteringen hos politiet?

	Vigtighed
Politistationernes tilgængelighed	
Atmosfæren og teknologi på politistationerne	
Ansvarsbevidsthed fra betjentene på politistationen	
Venlighed og empati fra betjentene på politistationen	
Retfærdighedssans fra betjentene på politistationen	

* 3. Hvordan opfatter du, vigtigheden af hvert af nedenstående emner, til at forbedre skadesanmeldelsen af trafikuheld til hospitalet?

	Vigtighed
Hospitalernes tilgængelighed	
Atmosfæren og teknologien på hospitalerne	
Ansvarsbevidsthed fra personalet på hospitalerne	
Venlighed og empati fra personalet på hospitalerne	
Retfærdighedssans fra personalet på hospitalerne	

Danmarks Tekniske Universitet DTU

Trafikuheldsrapportering

1: Politiets rolle ved trafikuheldsrapportering

Hvordan vurderer du, som en ekspert indenfor transport området, nedenstående faktorers rolle i forbindelse med uheldsrapportering hos politiet? Vi er interesseret i din mening, også selvom du ikke har tidligere erfaring med politiet.

* 4. Tilgængeligheden og atmosfæren hos politiet

	Nuværende situation i Danmark	Vurderede mulighed for forbedringer
Den gennemsnitlige rejsetid er kort til politistationen med bil fra bopæl		
Politiet kontaktes nemt i forbindelse med trafikuheldsrapportering		
Politiet besvarer telefonen indenfor rimelig tid		
Politiets ankomst til uheldsstedet sker indenfor rimelig tid		
Rene og rare venterum på politistationerne		
Stille og rolige omgivelserne på politistationerne		
Let afkrydsning via computer ved rapportering af trafikuheld		
Mængden af elektronisk dokumentation til korrekt rapportering		

* 5. Ansvarsbevidsthed, venlighed og retfærdighed hos politiet

	Nuværende situation i Danmark	Vurderede mulighed for forbedringer
Ventetiden er kort på politistationen ved trafikuheldsrapportering		
Politiet giver hurtig service ved trafikuheldsrapportering		
Politiet er gode til at give information ved trafikuheldsrapportering		
Politiet løser problemer ved trafikuheld effektivt		
Politiet er altid villige til at hjælpe ved trafikuheldsrapportering		
Politiet er generelt venlige og smilende		
Politiet behandler folk, der rapporterer trafikuheld, med respekt		
Politiets adfærd på politistationerne giver tryghed		
Politiet er gode til at forstå dine behov		
Betjente udpeget specifikt til håndtering af trafikuheldsrapportering		
Politiet er neutrale og retfærdige ved trafikuheldsrapportering		
Politiet dokumenterer trafikuheld præcist og korrekt i rapporten		
Politiet giver sig tid til trafikuheldsrapportering		

Danmarks Tekniske Universitet DTU

Trafikuheldsrapportering

2: Hospitalernes rolle ved skader pådraget i et trafikuheld

Hvordan vurderer du, som en ekspert indenfor transport området, nedenstående faktorers rolle i forbindelse med skadesanmeldelse til hospitalet? Vi er interesseret i din mening, også selvom du ikke tidligere har erfaring med hospitalet.

* 6. Tilgængelighed og atmosfæren på hospitalet

	Nuværende situation i Danmark	Vurderede mulighed for forbedringer
Den gennemsnitlige rejsetid er kort til hospitalet med bil fra bopæl		
Afstanden til hospitalet fra bopæl		
Man kan med lethed kontakte hospitalet		
Man kan med lethed blive henvist til hospitalet efter et trafikuheld		
Rene og rare venteværelserne på hospitalerne		
Omgivelserne på hospitalerne		
Tablets eller skærme til udpegning af uheldsstedet		
Let afkrydsning på computer til trafikuheldsrapportering		
Mængden af elektronisk dokumentation til korrekt rapportering		

* 7. Ansvarsbevidsthed, venlighed, empati og retfærdighed på hospitalet

	Nuværende situation i Danmark	Vurderede mulighed for forbedringer
Ventetiden er kort, ved lettere skader pådraget i et trafikuheld		
Ventetiden er kort, ved alvorligere skader pådraget i et trafikuheld		
Personalet har aldrig for travlt til at hjælpe med trafikuhelds-skader		
Personalet er generelt er høflige, venlige og smilene		
Personalet giver god information om trafikuhelds-rapportering		
Personalet giver støtte og omsorg til folk		
Personalet giver sig tid ved skadeanmeldelse af skader pådraget i et trafikuheld		
Personalet går op i en fejlfri og detaljeret skadeanmeldelse		
Personalet er gode til at forstå dine behov		
Personalet giver folk en ensartet behandling		
Personalet dokumenterer skader præcist og korrekt		
Personalet behandler folk uden fordomme		
Personalet bekymrer sig ikke om skyldspsørgsmålet		

Danmarks Tekniske Universitet DTU

Trafikuheldsrapportering

3: Normer og holdninger hos befolkningen ved trafikuhelds-rapportering

* 8. Hvad er din mening om sociale normer ved tidsbesparelse og skades vurdering af trafikuheld

	Procentdel af befolkningen der mener dette	Vurderede mulighed for forbedringerbedringer
Befolkningen synes, at deres arbejde er vigtigere end rapportering		
Befolkningen vil ikke bruge tid på at besøge egen læge		
Befolkningen rapporterer ikke, fordi de ikke får løn fra arbejdsgiver		
Befolkningen vil ikke rapporterer, hvis de ikke tror, de er kommet til skadet		
Befolkningen vil ikke melde et trafikuheld, hvis de ikke har smerter		
Befolkningen vil ikke rapporterer, hvis de ikke kan vurderer situationen		
Befolkningen vil ikke rapporterer, hvis lægen ikke anbefaler det		

Danmarks Tekniske Universitet DTU

Trafikuheldsrapportering

Hvordan forbedrer vi trafikuheldsrapportering?

* 9. Hvis du tager udgangspunkt i dine tidligere besvarelser, hvordan tror du da trenden for trafikuheldsrapportering vil blive i Danmark, hvis nogle faktorer bliver forbedret?

	Andel af uheld som vil blive rapporteret til myndighederne
Faktorer som har høj priotet og som er nemme at forbedre	
Faktorer som har høj priotet (uden hensyn til sværhedsgrad)	
Faktorer som er nemme at forbedre (uden hensyn til priotet)	
Alle faktorerne	

Danmarks Tekniske Universitet DTU

Trafikuheldsrapportering

Lidt om dig.....

* 10. Angiv venligst dit køn og din aldersgruppe

	Køn	Aldersgruppe
Køn og aldersgruppe		

* 11. Angiv venligst hvor i landet du primært arbejder

	Region
Arbejdsplads	

* 12. Angiv venligst hvilken interessentgruppe, der bedst beskriver dig

- ◯ Universitet eller forskningsenhed
- ◯ Konsulent i et privat firma
- ◯ Myndighed
- ◯ Transport leverandør
- ◯ NGO (ikke-statslig organisation)

Andet (angiv venligst)

* 13. Din interesse for trafiksikkerhed og trafikplanlægning i løbet af de sidste 10 år

	Slet ikke	Lidt	Noget	Meget	Virkelig meget
Jeg har arbejdet med uheldsanalyser og sortpletudpegning	○	○	○	○	○
Jeg har læst uheldsrapporter eller dokumenter om trafikuheld	○	○	○	○	○
Jeg har skrevet uheldsrapporter	○	○	○	○	○
Jeg er generelt interesseret i trafiksikkerhed	○	○	○	○	○
Jeg har arbejdet med trafiksikkerhedsrevisioner og -inspektioner	○	○	○	○	○
Jeg har arbejdet med trafiksikkerhedsplaner og sikrer veje	○	○	○	○	○
Jeg har arbejdet med trafiksikkerhedskampagner	○	○	○	○	○

* 14. Har du besøgt en politistation eller hospitalet indenfor de sidste 5 år?

- ○ Nej
- ○ Ja, kun politistationen
- ○ Ja, kun hospitalet
- ○ Ja, begge steder

* 15. Har du haft et trafikuheld inden for de sidste 5 år?

- ○ Nej
- ○ Ja, men jeg rapporterede det ikke
- ○ Ja, og jeg rapporterede det til politiet
- ○ Ja, og jeg rapporterede det til hospitalet

Danmarks Tekniske Universitet DTU

Trafikuheldsrapportering

Mange tak for hjælpen!

16. Hvis du vil deltage i konkurrencen, så skriv dit navn og Email-adresse, så vi kan kontakte dig, hvis du vinder:

Navn og efternavn:

Email:

17. Hvis du har nogle kommentarer, er du velkommen til at skrive dem her

Appendix 3: Questionnaire for decision makers

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Indrapportering af trafikuheld

Underrapportering af trafikulykker er et stort problem i Danmark, hvor kun 21% af alle trafikuheld, som indrapporteres til hospitalet, også er at finde i de officielle uheldsdata indsamlet af politiet.

Din besvarelse af dette spørgeskema er vigtig for os! Vi har tillid til, at dine synspunkter, som ekspert indenfor transport området, kan skaffe viden om, hvordan man kan løse problemet med underrapportering af trafikulykker.

Vi beder dig derfor udfylde det selvom du ikke har personlig erfaring med at indrapportere et trafikuheld. I det tilfælde vil vi bede dig om at benytte dit generelle kendskab til politi- og hospitalsvæsen til besvarelsen.

Besvarelsen tager ca. 10 minutter. Som tak for hjælpen udlodder vi:

5 x 800 kr. gavekort til restaurantbesøg.

Vinderen bliver trukket blandt de personer, der har angivet deres navn og e-mailadresse.

Dette spørgeskema er en del af et Ph.d.-projekt, som er en del af et større projekt (IMPROSA) på DTU Transport og har til mål at forbedre trafiksuheldrapporteringen i Danmark.

Ved spørgsmål omkring spørgeskemaet henvises til Kira Janstrup: kj@transport.dtu.dk.

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Indrapportering af trafikuheld

Lidt om dig.....

* 1. Angiv venligst dit køn og din aldersgruppe

	Køn	Aldersgruppe
Køn og aldersgruppe		

* 2. Angiv venligst hvor i landet du primært arbejder

	Region
Arbejdsplads	

* 3. Angiv venligst hvilken interessentgruppe, der bedst beskriver dig

- ◯ Universitet eller forskningsenhed
- ◯ Konsulent i et privat firma
- ◯ Myndighed
- ◯ Transport leverandør
- ◯ NGO (ikke-statslig organisation)

Andet (angiv venligst)

* 4. Din interesse for trafiksikkerhed og trafikplanlægning i løbet af de sidste 10 år

	Slet ikke	Lidt	Noget	Meget	Virkelig meget
Jeg har arbejdet med uheldsanalyser og sortpletudpegning	○	○	○	○	○
Jeg har læst uheldsrapporter eller dokumenter om trafikuheld	○	○	○	○	○
Jeg har skrevet uheldsrapporter	○	○	○	○	○
Jeg er generelt interesseret i trafiksikkerhed	○	○	○	○	○
Jeg har arbejdet med trafiksikkerhedsrevisioner og -inspektioner	○	○	○	○	○
Jeg har arbejdet med trafiksikkerhedsplaner og sikre veje	○	○	○	○	○
Jeg har arbejdet med trafiksikkerhedskampagner	○	○	○	○	○

* 5. Har du, som privat person, besøgt en politistation eller hospitalet indenfor de sidste 5 år?

- ○ Nej
- ○ Ja, kun politistationen
- ○ Ja, kun hospitalet
- ○ Ja, begge steder

* 6. Har du haft et trafikuheld inden for de sidste 5 år?

- ○ Nej
- ○ Ja, men jeg var ikke i kontakt med hverken politiet eller hospitalet
- ○ Ja, og jeg var i kontakt med politiet
- ○ Ja, og jeg var i kontakt med hospitalet

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Indrapportering af trafikuheld

* 7. Synes du, at det er vigtigt, at folk kontakter politiet eller hospitalet i forbindelse med et trafikuheld?

	Slet ikke vigtig	Ikke vigtig	Hverken/ eller	Vigtigt	Meget vigtig
Politiet	◯	◯	◯	◯	◯
Hospitalet	◯	◯	◯	◯	◯

* 8. Hvordan opfatter du, vigtigheden af hvert af nedenstående emner, for at forbedre trafikuheldsrapporteringen hos politiet?

	Slet ikke vigtig	Ikke vigtig	Hverken/ eller	Vigtigt	Meget vigtig
Politistationernes tilgængelighed	◯	◯	◯	◯	◯
Atmosfæren og teknologi på politistationerne	◯	◯	◯	◯	◯
Ansvarsbevidsthed fra betjentene på politistationen	◯	◯	◯	◯	◯
Venlighed og empati fra betjentene på politistationen	◯	◯	◯	◯	◯
Retfærdighedssans fra betjentene på politistationen	◯	◯	◯	◯	◯

* 9. Hvordan opfatter du, vigtigheden af hvert af nedenstående emner, til at forbedre skadesanmeldelsen af trafikuheld til hospitalet?

	Slet ikke vigtig	Ikke vigtig	Hverken/ eller	Vigtigt	Meget vigtig
Hospitalernes tilgængelighed	◯	◯	◯	◯	◯
Atmosfæren og teknologien på hospitalerne	◯	◯	◯	◯	◯
Ansvarsbevidsthed fra personalet på hospitalerne	◯	◯	◯	◯	◯
Venlighed og empati fra personalet på hospitalerne	◯	◯	◯	◯	◯
Retfærdighedssans fra personalet på hospitalerne	◯	◯	◯	◯	◯

Danmarks Tekniske Universitet DTU

Indrapportering af trafikuheld

1: Politiets rolle ved trafikuheldsrapportering

Hvordan vurderer du, som en ekspert indenfor transport området, nedenstående udsagns rolle i forbindelse med uheldsrapportering hos politiet? Vi er interesseret i din mening, også selvom du ikke har tidligere erfaring med politiet.

* 10. Hvor sikker føler du dig på dit generelle standpunkt omkring uheldsrapportering til politiet?

- ◯ Lidt
- ◯ Noget
- ◯ En del
- ◯ Meget
- ◯ Ekstremt meget

* 11. Hvordan vurderer du nedenstående udsagns rolle i forbindelse med uheldsrapportering hos politiet? (Tilgængelighed, teknologi og atmosfære)

	Slet ikke vigtig	Ikke vigtig	Hverken/eller	Vigtigt	Meget vigtig
Den gennemsnitlige rejsetid er kort til politistationen med bil fra bopæl	◯	◯	◯	◯	◯
Politiet kontaktes nemt i forbindelse med trafikuheldsrapportering	◯	◯	◯	◯	◯
Politiet besvarer telefonen indenfor rimelig tid	◯	◯	◯	◯	◯
Politiets ankomst til uheldsstedet sker indenfor rimelig tid	◯	◯	◯	◯	◯
Rene og rare venterum på politistationerne	◯	◯	◯	◯	◯
Stille og rolige omgivelserne på politistationerne	◯	◯	◯	◯	◯
Let afkrydsning via computer ved rapportering af trafikuheld	◯	◯	◯	◯	◯
Mængden af elektronisk dokumentation til korrekt rapportering	◯	◯	◯	◯	◯

* 12. Hvordan vurderer du nedenstående udsagns rolle i forbindelse med uheldsrapportering hos politiet? (Ansvarsbevidsthed, venlighed og retfærdighed)

	Slet ikke vigtig	Ikke vigtig	Hverken/eller	Vigtigt	Meget vigtig
Ventetiden er kort på politistationen ved trafikuheldsrapportering	○	○	○	○	○
Politiet giver hurtig service ved trafikuheldsrapportering	○	○	○	○	○
Politiet er gode til at give information ved trafikuheldsrapportering	○	○	○	○	○
Politiet løser problemer ved trafikuheld effektivt	○	○	○	○	○
Politiet er altid villige til at hjælpe ved trafikuheldsrapportering	○	○	○	○	○
Politiet er generelt venlige og smilende	○	○	○	○	○
Politiet behandler folk, der rapporterer trafikuheld, med respekt	○	○	○	○	○
Politiets adfærd på politistationerne giver tryghed	○	○	○	○	○
Politiet er gode til at forstå dine behov	○	○	○	○	○
Betjente udpeget specifikt til håndtering af trafikuheldsrapportering	○	○	○	○	○
Politiet er neutrale og retfærdige ved trafikuheldsrapportering	○	○	○	○	○
Politiet dokumenterer trafikuheld præcist og korrekt i rapporten	○	○	○	○	○
Politiet giver sig tid til trafikuheldsrapportering	○	○	○	○	○

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Indrapportering af trafikuheld

2: Hospitalernes rolle ved skader pådraget i et trafikuheld

Hvordan vurderer du, som en ekspert indenfor transport området, nedenstående udsagns rolle i forbindelse med skadesanmeldelse til hospitalet? Vi er interesseret i din mening, også selvom du ikke tidligere har erfaring med hospitalet.

* 13. Hvor sikker føler du dig på dit generelle standpunkt omkring skadesanmeldelse til hospitalet?

- ◯ Lidt
- ◯ Noget
- ◯ En del
- ◯ Meget
- ◯ Ekstremt meget

* 14. Hvordan vurderer du nedenstående udsagns rolle i forbindelse med skadesanmeldelse til hospitalet? (Tilgængelighed, teknologi og atmosfære)

	Slet ikke vigtig	Ikke vigtig	Hverken/eller	Vigtigt	Meget vigtig
Den gennemsnitlige rejsetid er kort til hospitalet med bil fra bopæl	◯	◯	◯	◯	◯
Afstanden til hospitalet fra bopæl	◯	◯	◯	◯	◯
Man kan med lethed kontakte hospitalet	◯	◯	◯	◯	◯
Man kan med lethed blive henvist til hospitalet efter et trafikuheld	◯	◯	◯	◯	◯
Rene og rare venteværelserne på hospitalerne	◯	◯	◯	◯	◯
Omgivelserne på hospitalerne	◯	◯	◯	◯	◯
Tablets eller skærme til udpegning af uheldsstedet	◯	◯	◯	◯	◯
Let afkrydsning på computer til trafikuheldsrapportering	◯	◯	◯	◯	◯
Mængden af elektronisk dokumentation til korrekt rapportering	◯	◯	◯	◯	◯

* 15. Hvordan vurderer du nedenstående udsagns rolle i forbindelse med skadesanmeldelse til hospitalet? (Ansvarsbevidsthed, venlighed, empati og retfærdighed)

	Slet ikke vigtig	Ikke vigtig	Hverken/eller	Vigtigt	Meget vigtig
Ventetiden er kort, ved lettere skader pådraget i et trafikuheld	○	○	○	○	○
Ventetiden er kort, ved alvorligere skader pådraget i et trafikuheld	○	○	○	○	○
Personalet har aldrig for travlt til at hjælpe med skader pådraget i et trafikuheld	○	○	○	○	○
Personalet er generelt er høflige, venlige og smilene	○	○	○	○	○
Personalet giver god information om trafikuhelds-rapportering	○	○	○	○	○
Personalet giver støtte og omsorg til folk	○	○	○	○	○
Personalet giver sig tid ved skadeanmeldelse af skader pådraget i et trafikuheld	○	○	○	○	○
Personalet går op i en fejlfri og detaljeret skadeanmeldelse	○	○	○	○	○
Personalet er gode til at forstå dine behov	○	○	○	○	○
Personalet giver folk en ensartet behandling	○	○	○	○	○
Personalet dokumenterer skader præcist og korrekt	○	○	○	○	○
Personalet behandler folk uden fordomme	○	○	○	○	○
Personalet bekymrer sig ikke om skyldspsørgsmålet	○	○	○	○	○

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Indrapportering af trafikuheld

Hvordan forbedrer vi trafikuheldsrapportering?

* 16. Synes du, at der er mulighed for forbedringer ved indrapportering af trafikuheld til politiet og skader pådraget i trafikuheld til hospitalet?

	Lidt	Noget	En del	Meget	Ekstremt meget
Politiet	◯	◯	◯	◯	◯
Hospitalet	◯	◯	◯	◯	◯

* 17. Hvor meget tror du trafikuheldsrapporteringen vil kunne øges i Danmark, hvis følgende faktorer bliver forbedret?

	Lidt	Noget	En del	Meget	Ekstremt meget
Politistationernes tilgængelighed	◯	◯	◯	◯	◯
Atmosfære og teknologi på politistationerne	◯	◯	◯	◯	◯
Ansvarsbevidsthed fra betjentene på politistationen	◯	◯	◯	◯	◯
Venlighed og empati fra betjentene på politistationen	◯	◯	◯	◯	◯
Retfærdighedssans fra betjentene på politistationen	◯	◯	◯	◯	◯
Hospitalernes tilgængelighed	◯	◯	◯	◯	◯
Atmosfære og teknologi på hospitalerne	◯	◯	◯	◯	◯
Ansvarsbevidsthed fra personalet på hospitalerne	◯	◯	◯	◯	◯
Venlighed og empati fra personalet på hospitalerne	◯	◯	◯	◯	◯
Retfærdighedssans fra personalet på hospitalerne	◯	◯	◯	◯	◯

Danmarks Tekniske Universitet DTU

Indrapportering af trafikuheld

Mange tak for hjælpen!

18. Hvis du vil deltage i konkurrencen, så skriv dit navn og Email-adresse, så vi kan kontakte dig, hvis du vinder:

Navn og efternavn:

Email:

19. Hvis du har nogle kommentarer, er du velkommen til at skrive dem her

PAPER 1

Understanding traffic crash under-reporting: Linking police and medical records to individual and crash characteristics

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Abstract

Objective. This study aligns to the body of research dedicated to estimating the under-reporting of road crash injuries and adds the perspective of understanding individual and crash factors contributing to the decision to report a crash to the police, the hospital, or both.

Method. This study focuses on road crash injuries that occurred in the province of Funen (Denmark) between 2003 and 2007 and were registered in the police, the hospital, or both authorities. Under-reporting rates are computed with the capture-recapture method, and the probability for road crash injuries in police records to appear in hospital records (and vice versa) is estimated with joint binary logit models.

Results. The capture-recapture analysis shows high under-reporting rates of road crash injuries in Denmark, and the growth of under-reporting not only with the decrease of injury severity, but also with the involvement of cyclists (reporting rates about 14% for serious injuries and 7% for slight injuries) and motorcyclists (reporting rates about 35% for serious injuries and 10% for slight injuries). Model estimates show that the likelihood of appearing in both datasets is positively related to helmet and seat-belt use, number of motor vehicles involved, alcohol involvement, higher speed limit, and females being injured.

Conclusions. This study adds significantly to the literature about under-reporting by recognizing that understanding the heterogeneity in the reporting rate of a road crash may lead to devising policy measures aimed at increasing the reporting rate by targeting specific road user groups (e.g., males, young road users) or specific situational factors (e.g., slight injuries, arm injuries, leg injuries, weekend).

Keywords: Crash Under-Reporting; Police Reports; Hospital Reports; Capture-Recapture Method; Joint Model Estimation.

1. Introduction

The estimation of the number of road crash injuries and the analysis of their severity have received a lot of attention in recent years, but their reliance on police reports makes them subject to bias because of the severe under-reporting (e.g., Elvik & Mysen, 1999; Farmer, 2003; McDonald et al., 2009). A meta-analysis of studies about crash under-reporting showed that the official road crash statistics in Denmark contain only 21% of the hospital crash injuries, a staggering result when compared to rates between 25% and 88% for other countries included in the meta-analysis and between 25% and 57% in other European countries (Elvik & Mysen, 1999). Under-reporting rates vary considerably with the injury severity level and the road user type (e.g., Elvik & Mysen, 1999; Farmer, 2003; McDonald et al., 2009), and comparing police and hospital records in Denmark revealed that the police reports 97% of the fatalities, but only 48% of car occupant injuries and 10% of cyclist injuries (Elvik & Mysen, 1999).

Under-reporting rates are traditionally computed with the capture-recapture method that estimates the share of overlapping records in two different samples not representing the full population, while assuming sampling independence and homogeneity. The method has been criticized because of the inevitable violation of the two assumptions when computing road crash injuries: (i) sampling dependency occurs when the police calls emergency medical services and causes road crash injury under-estimation; (ii) sampling heterogeneity motivates stratification by injury severity level and road user type and causes road crash injury over-estimation (Jarvis et al. 2007). Accordingly, most studies focused on subgroups of road crashes involving children or adolescents (Roberts & Scragg, 1994; Morrison & Stone, 2000; Dhillon et al., 2001), pedestrians or cyclists (Roberts & Scragg, 1994; Dhillon et al., 2001; Tin et al., 2013), heavy vehicles (Meuleners et al., 2006), work-related vehicles (Thomas et al., 2012), and alcohol (Miller et al., 2012). Several studies focused only on fatalities (Lateef et al., 2010; Kudryatsev et al., 2013) or serious injuries (Amoros et al., 2007), and only a few studies covered all injury and road user types (Aptel et al., 1999; Tercero & Andersson, 2004; Abegaz et al., 2014; Yannis et al., 2014; Watson et al., 2015). While modelling approaches have tackled sampling heterogeneity by analysing the probability of hospital records being reported to the police (Yannis et al., 2014; Watson et al., 2015), the probability of police records being reported to hospitals has not been analysed.

This study proposes the computation of under-reporting rates in Denmark from police and hospital records and analyses the determinants of reporting to the police, the hospital, or both. This study hypothesizes that under-reporting exists in both sources and hence extends existing literature by looking at police records not reported to hospitals alongside hospital records not reported to the police. Data consist of police reports maintained by the Danish Road Directorate and hospital reports collected in the Danish province of Funen between 2003 and 2007. As the hospitals are under the national healthcare system and the national police operate in all Danish regions, the under-reporting rates in Funen are a reliable estimate of the rates in Denmark. The under-reporting rate of road crash injuries is computed with the capture-recapture

method from police and hospital records matched according to a (pseudo) civil registration number from the Danish Bureau of Statistics. The likelihood of reporting road crashes to the police and hospitals is investigated with a joint binary logit model as a function of individual and crash characteristics and not only trauma type and severity. Model estimation allows comprehending the reasons for road crash injuries appearing in the hospital and/or police records, and understanding the heterogeneity in the reporting to the two authorities is essential for devising policy measures aimed at increasing the reporting rate by targeting specific road user groups or situational factors.

2. Methods

2.1. Data

There were 27,199 road crash injuries reported to the hospitals or the police in Funen in the years 2003 to 2007: 12,637 appeared in the police records, 18,896 appeared in the hospital records, and only 4,334 appeared in both. Crashes involving motorized vehicles as well as solo cyclist crashes were included: of the latter, 4,963 were reported to the hospital, 92 to the police, and 132 to both. The police records were obtained from the Danish Road Directorate, which is the governmental agency that collects police reports on road crashes in Denmark. Police reports include crash characteristics (e.g., roadway characteristics, surface conditions, weather conditions, speed limits), crash location (e.g., intersection, section, municipality), vehicles involved (e.g., make, model), and road users involved (e.g., civil registration number, injury degree, age, gender, residence). The hospital records were collected at three hospitals covering all of Funen (Odense, Svendborg and Middelfart). Hospital records include an AIS (Abbreviated Injury Scale) code with diagnosis codes related to trauma type, crash characteristics (e.g., number of vehicles involved, the involvement of vulnerable road users, crash location) and personal information of the patients (e.g., civil registration number, age, gender). Notably, road users can voluntarily report to the police or the hospital any road crash defined as an incident that happened on a road or place used by regular traffic and where at least one of the involved road users is a car driver, motorcyclist or cyclist. When called, police officers report the crash when there are injuries or material damage exceeding 7,500 USD per vehicle. When admitted to hospitals, medical personnel reports the crash also for suspected injuries. As the Danish healthcare system is public, hospital compile records from both self-admittance and general physician referral and hence merging multiple hospital sources (Watson et al., 2015) is not required.

Injury severity levels are coded differently in the two databases. The police uses a 4-step scale where no injuries correspond to property damage and bruises, slight injuries require medical treatment, severe injuries result in temporary or permanent incapacity, and fatalities occur within 30 days from the crash. The hospital uses a 6-step AIS scale (Leth & Ibsen, 2010). Accordingly, the end result of the hospitalization is transformed into a 4-step injury scale to mimic the police scale and include injury

severity in the analysis: ISS 1 was assigned to “no (or minor) injury”, ISS 2 to 4 were assigned to “slight injury”, and ISS over 5 was assigned to “severe injury” (Abay, 2015).

Records are linked between the two databases via the individual (pseudo) civil registration number of the person involved in the road crash as recorded by the Danish Bureau of Statistics. This procedure obviates possible biases introduced by matching characteristics (e.g., date, gender, age) between police and hospital records (e.g., Amoros et al., 2006; Meuleners et al., 2006; Lateef et al., 2010; Thomas et al., 2012) that could imply false positive identification of matching records when they are highly similar but do not derive from the same road crash. Also, both databases are complete and accurate since police officers attend regular training courses for crash reports and follow strict reporting guidelines, while hospital personnel has specific training in classifying injuries and screening for suicides and sudden deaths before the road crash.

2.2. Capture-recapture method

Under-reporting rates are estimated with the capture-recapture method commonly used in ecology to estimate animal population size and in epidemiology to estimate disease spread. The method estimates the share of overlapping records in two independent samples (see Figure 1) while assuming that (i) the population is finite and closed, (ii) common records are unambiguously identified, (iii) records are independent, and (iv) records are homogeneously catchable.

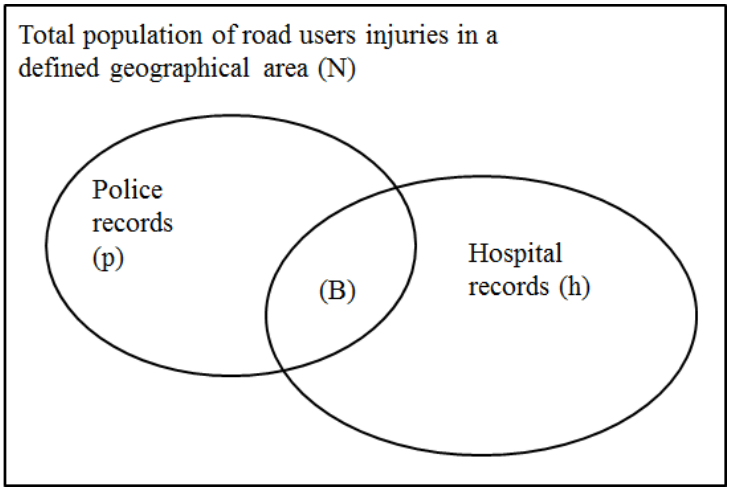

Figure 1: The capture-recapture method

A two sampled capture-recapture method estimates the total number N of road crash injuries in Funen by applying the Chapman capture-recapture formulary:

$$N = \frac{(p+1)(h+1)}{(B+1)} - 1 \qquad (1)$$

where p are the road crash injuries in the police reports, h are the road crash injuries in the hospital reports, and B are the road crash injuries in both reports. Variance and

95% confidence interval for the estimate of N are calculated as:

$$Var(N) = \frac{(p+1)(h+1)(p-B)(h-B)}{(B+1)^2(B+2)} \quad (2)$$

$$95\%\ CI(N) = N \pm 1.96\sqrt{Var(N)} \quad (3)$$

In this study, the first assumption is plausible, as the records have been approved for release by the police and the hospitals, and the second assumption is met, as the (pseudo) civil registration number unambiguously links the road crash injuries in both databases. The third assumption is likely violated, in the case that the police informs the hospital about a road crash, and the fourth assumption is violated, as under-reporting is not random. This violation motivates the investigation of the heterogeneity in the reporting with a discrete choice model approach.

2.3. Joint binary logit model

A binary logit model estimates the probability that a road crash injury n appears in the database M given that the same road crash injury appears in the other database. While previous studies investigated the under-reporting of police records in hospital records (Yannis et al., 2014; Watson et al., 2015), this study examines also the under-reporting of hospital records in police records and hence overcomes the incorrect assumption that either sample represents the entire population.

The probability that a road crash injury *n* in one database appears in the other is a function of a vector X_{ni}^M of observable variables that include person characteristics, vehicles involved and injury severity (Watson et al., 2015). While repeated involvement of the same road user in multiple crashes could violate the sampling independence assumption, in this study (i) only 2% of road users appeared in multiple crashes, (ii) 80% of these cases occurred over one year apart, (iii) 90% of these cases involved different third parties, and (iv) 99% of these cases had different severity outcomes. Accordingly, the assumption of sampling independence is reasonable. Given the police database *P* and the hospital database *H*, the probabilities P_{ni}^P and P_{ni}^H of observing a registration match for road crash injury n are expressed as a function of vectors of observable variables X_{ni}^P and X_{ni}^H and vectors of parameters β_P and β_H:

$$P_{ni}^P = \frac{\exp\left(\beta_P X_{ni}^P\right)}{\exp\left(\beta_P X_{ni}^P\right) + \exp\left(\beta_H X_{ni}^H\right)} \quad (1)$$

$$P_{ni}^H = \frac{\exp\left(\beta_P X_{ni}^H\right)}{\exp\left(\beta_P X_{ni}^P\right) + \exp\left(\beta_H X_{ni}^H\right)} \quad (2)$$

Estimates of the vectors β_P and β_H provides insights into the determinants of police records being registered also in the hospital and vice versa. However, the estimates cannot be compared because their differences could result from differences in utility

parameters and scale factors, and hence the scale factors μ^P and μ^H should be estimated with the vectors β_P and β_H. Accordingly, this study considers the two utility functions U_{ni}^P and U_{ni}^H for the joint estimation of two models:

$$U_{ni}^P = V_{ni}^P + \varepsilon_{ni}^P = \beta X_{ni}^{PH} + \alpha W_{ni}^P + \varepsilon_{ni}^P \quad (7)$$

$$U_{ni}^H = V_{ni}^H + \varepsilon_{ni}^H = \beta X_{ni}^{PH} + \gamma Z_{ni}^H + \varepsilon_{ni}^H \quad (8)$$

where X_{ni}^{PH} is a vector of observable variables common to both databases, W_{ni}^P is a vector of observable variables specific to the police database, Z_{ni}^H is a vector of observable variables specific to the hospital database, ε_{ni}^P and ε_{ni}^H are vectors of i.i.d. Gumbel error terms, and β, α and γ are vectors of parameters to be estimated.

The estimation of the joint binary logit models provides insight into the differences between the scale factors μ^P and μ^H whose ratio is estimated by normalizing the variance of the error ε^P to unity and identifying the relative variance or scale for the error ε^H (Hensher et al., 1999). Estimation is performed by maximum likelihood and produces the estimates of the elements of vectors β, α, and γ, as well as the scalar μ^P.

3. Results

3.1. Capture-Recapture Computation

Table 1 presents the results of the application of the capture-recapture method in order to estimate the total number of road crash injuries or suspected injuries in Funen for each of the years from 2003 to 2007. Material damage only crashes from the police were included, as some of the road users involved in those actually were also included in the hospital records.

Table 1: Number of road users involved in a road crash by year

Year	Matched	Unmatched in police data	Unmatched in ER data	Capture (95% CI)
2003	927	1,812	2,927	11,381 (10,863-11,900)
2004	848	1,631	3,033	11,339 (10,729-11,885)
2005	778	1,499	2,872	10,675 (10,136-11,215)
2006	876	1,558	2,769	10,122 (9,655-10,589)
2007	905	1,803	2,961	11,562 (11,024-12,099)

Table 2 presents the results of the capture-recapture method when road crash injuries are differentiated according to the degree of injury severity. The number of road fatalities in Funen varies between 25 and 39 in the period from 2003 to 2007, while the number of severe injuries varies between 1,190 in 2006 and 1,408 in 2003, and the number of slight injuries varies from 2,142 in 2006 to 2,317 in 2007. Expectedly, the under-reporting in the police records is significantly higher than the one in the hospital records.

Table 2: Number of road users involved in a road crash by year, divided by degree of injury severity, transport mode

	Year	Matched	Unmatched in police data	Unmatched in ER data	Capture (95% CI)
Fatal	2003	19	9	1	29 (28-31)
	2004	19	8	0	27 (27-27)
	2005	18	7	0	25 (25-25)
	2006	28	3	1	32 (31-33)
	2007	27	8	3	39 (37-41)
Severe	2003	448	111	681	1,408 (1,363-1,453)
	2004	398	68	743	1,336 (1,295-1,376)
	2005	362	68	683	1,241 (1,200-1,282)
	2006	410	61	626	1,190 (1,158-1,222)
	2007	433	88	640	1,291 (1,252-1,329)
Slight/ Suspected injury	2003	460	113	2,244	3,367 (3,243-3,491)
	2004	431	95	2,289	3,318 (3,197-3,440)
	2005	398	73	2,189	3,060 (2,952-3,169)
	2006	438	83	2,142	3,068 (2,964-3,172)
	2007	445	100	2,317	3,382 (3,259-3,504)

Table 3 illustrates the reporting rate recorded by the police for each transport mode. The results show that the police reports only about 6-7% of all slightly injured cyclists and 14-15% of all severely injured cyclists involved in a road crash in Funen. The problem is common to other vulnerable road users, as the police records only about 6-10% of the slightly injured and 27-44% of the seriously injured motorcyclists. Interestingly, the police records between 0% and 13% of the slight injuries and between 6% and 18% of the severe injuries on buses.

Table 3: Number of road users involved in a road crash by year, divided by degree of injury severity, transport mode and police report rate

		Fatal		Severe		Slight/ Suspected injury	
Transport mode	Year	Capture (95% CI)	Police catch rate (%)	Capture (95% CI)	Police catch rate (%)	Capture (95% CI)	Police catch rate (%)
Pedestrian	2003	1 (1-1)	100	65 (57-73)	60	130 (101-158)	22
	2004	2 (2-2)	100	83 (73-93)	52	111 (96-125)	32
	2005	6 (6-6)	100	50 (46-55)	46	90 (73-108)	18
	2006	3 (3-3)	100	65 (58-72)	60	101 (80-122)	26
	2007	5 (5-5)	100	66 (60-73)	62	120 (93-146)	23
Cyclist	2003	6 (6-6)	83	669 (609-739)	15	1,712 (1,559-1,865)	6
	2004	9 (9-9)	100	637 (688-686)	14	1,562 (1,446-1,679)	6
	2005	4 (4-4)	100	612 (557-668)	14	1,478 (1,376-1,579)	7
	2006	4 (4-4)	100	490 (457-524)	14	1,344 (1,252-1,435)	6
	2007	3 (3-3)	100	582 (522-642)	14	1,459 (1,334-1,585)	7
Moped	2003	4 (4-4)	100	192 (175-209)	52	291 (253-329)	23

	2004	6 (6-6)	100	212 (190-233)	40	292 (253-331)	23
	2005	2 (2-2)	100	172 (157-187)	41	276 (236-315)	20
	2006	6 (6-6)	100	179 (164-195)	47	321 (279-363)	22
	2007	6 (6-6)	100	201 (186-217)	48	330 (297-363)	26
Motor-Cyclist	2003	2 (2-2)	100	68 (60-76)	35	116 (92-140)	10
	2004	0 (0-0)	N/A	74 (63-84)	27	154 (115-194)	6
	2005	0 (0-0)	N/A	70 (58-83)	38	131 (99-164)	10
	2006	5 (5-5)	100	61 (54-68)	44	162 (92-232)	7
	2007	3 (3-3)	100	77 (67-87)	44	118 (93-143)	7
Car	2003	15 (15-15)	100	361 (351-371)	73	982 (945-1,018)	31
	2004	8 (8-8)	100	291 (285-297)	67	1,018 (976-1,060)	28
	2005	12 (12-12)	100	293 (284-302)	67	907 (871-942)	27
	2006	10 (9-11)	89	320 (313-326)	66	997 (964-1,030)	28
	2007	19 (17-21)	85	349 (340-358)	68	1,159 (1,113-1,204)	25
Bus	2003	0 (0-0)	N/A	14(6-22)	14	40 (27-52)	13
	2004	0 (0-0)	N/A	10 (10-10)	10	49 (17-80)	4
	2005	0 (0-0)	N/A	17 (17-17)	6	39 (39-39)	5
	2006	0 (0-0)	N/A	12 (12-12)	17	28 (28-28)	11
	2007	1 (1-1)	0	11 (11-11)	18	47 (47-47)	0
Other*	2003	1 (1-1)	100	42 (38-45)	72	78 (70-87)	56
	2004	2 (2-2)	100	38 (36-40)	79	48 (45-52)	41
	2005	1 (1-1)	100	39 (37-42)	74	78 (71-84)	45
	2006	4 (4-4)	100	45 (43-47)	81	71 (64-78)	49
	2007	2 (2-2)	100	31 (29-32)	82	78 (67-90)	36

* Include road users of van, tractor and truck.
** 31 road users in the police registration only are not included in this table because of missing information on the transport mode.

3.2. Joint Model Estimation

Table 4 presents the estimation of the joint binary logit models expressing the likelihood that a road user involved in a road crash reported to the police appears also in the hospital records, and vice versa. Given missing information, only 26,052 road users were considered for model estimation, with 18,263 in the hospital records, 12,062 in the police records, and 4,273 in both databases.

Table 4: Estimates of the joint model of the probability that a road user involved in a road crash with injury or suspected injury reported to the hospital appears in the police records, and vice versa

		Reported in H appears in P		Reported in P appears in H	
Variable	Category	Estimate	t-stat	Estimate	t-stat
Gender	Male	-0.603	-14.23	-0.895	-16.88
	Female	-	-	-	-
Age	Less than 18 years old	-	-	-	-
	18-24 years old	-0.872	-13.12	-0.755	-9.10

	25-34 years old	-0.916	-13.18	-0.941	-10.72
	35-44 years old	-0.910	-13.07	-0.979	-11.03
	45-54 years old	-0.855	-11.35	-1.010	-10.59
	55-64 years old	-0.854	-10.32	-0.979	-9.53
	65-74 years old	-0.723	-7.05	-0.740	-5.85
	Over 75 years old	-0.831	-7.17	-0.623	-4.44
Injury severity	Minor	-	-	-	-
	Serious	1.600	30.64	2.510	25.20
	Fatal	5.210	9.72	2.740	10.28
Road user type	Pedestrian	1.270	11.53	0.556	3.68
	Cyclist	-0.345	-5.00	-0.546	-5.66
	Moped	0.870	8.74	-0.883	-6.64
	Motorcyclists	0.263	1.84	-1.280	-6.63
	Car	-	-	-	-
	Van	0.889	4.59	0.819	3.91
	Heavy vehicle	-0.999	-6.02	-0.987	-5.38
Seatbelt	Yes	2.170	34.60	2.090	26.75
	No	-	-	-	-
Helmet	Yes	0.515	6.23	2.010	20.26
	No	-	-	-	-
Family status	Single	-2.650	-35.95	-2.430	-26.91
	Partner	-2.930	-42.02	-2.730	-31.42
	Other status	-	-	-	-
Other parties involved	Zero	-	-	-	-
	One	1.070	18.01	0.253	3.29
	Two	0.863	11.43	0.315	3.03
	Three or more	1.010	12.40	0.572	5.30
Type of injury	Head	1.110	19.08	-	-
	Head and thorax	1.600	9.20	-	-
	Head and upper extremities	1.710	16.92	-	-
	Head and lower extremities	1.980	18.09	-	-
	Head and spine	2.710	16.79	-	-
	Thorax	1.630	13.56	-	-
	Thorax and upper extremities	1.480	7.39	-	-
	Thorax and lower extremities	2.110	11.80	-	-
	Thorax and spine	2.220	9.36	-	-
	Upper extremities	-	-	-	-
	Upper extremities and spine	2.690	11.39	-	-
	Lower extremities	0.880	13.12	-	-
	Lower extremities and spine	3.120	12.86	-	-
	Spine	2.240	19.35	-	-
Education	Low education	-	-	-	-
	Medium education	-	-	0.050	0.34
	High education	-	-	-0.008	-0.13
Speed limit	Less than 70 km/h	-	-	-	-
	70-90 km/h	-	-	1.160	17.11

	100-130 km/h	-	-	1.370	9.84
Number of lanes	One	-	-	-	-
	Two	-	-	3.510	36.96
	Three or more	-	-	3.510	29.57
Type of day	Weekend	-	-	-0.085	-1.62
	Weekday	-	-	-	-
Time of day	Morning peak	0.107	1.78	0.211	3.02
	Other periods	-	-	-	-
Season	Spring	-0.744	-13.10	-0.614	-9.22
	Summer	-	-	-	-
	Autumn	-0.703	-13.00	-0.606	-9.45
	Winter	-0.739	-12.77	-0.539	-8.01
Scale parameter		1.000	-	0.886	-7.73*
Log-likelihood at zero					-33315.148
Log-likelihood at convergence					-15639.149
Adjusted Rho-bar squared					0.528

Note: * t-test with respect to 1 (tests the equality of the scale parameters)

The estimates uncover similarities in the matching likelihood. The probability of being recorded in both datasets is lower for males and higher for people under 18 years old. The likelihood for road crash injuries to appear in both datasets increases for severe crashes, seatbelt and helmet use, and morning peak crashes. Moreover, comparable seasonal effects are observed, as reporting from police to hospital and vice versa seems more likely in the summer with respect to colder seasons.

Interestingly, the estimates reveal differences in the matching likelihood. With respect to car occupants, pedestrians are more likely to appear in both databases and cyclists are more likely to appear in either database regardless of analysing the reporting to the police or the hospitals. With respect to car occupants however, moped riders and motorcyclists are under-reported when checking whether police records appear in the hospital database, and over-reported when controlling whether hospital records appear in the police database. When considering the number of parties involved, both models express the same tendence but the likelihood of hospital records appearing in the police ones appears higher. In the hospital records, injuries to head, thorax and spine are more likely to be related to an increase in the probability of the crashes being also in the police records, in particular when spinal injuries are recorded. In the police records, there is not a significant effect of the level of education of the road user in reporting the crash also to the hospital, while larger roads and higher speed limits have an effect on the likelihood of reporting the police record also to the hospital.

Lastly, the estimation of the scale factor μ^P with respect to the normalized scale factor μ^H is significantly lower than 1 and indicates higher variance of the error term ε^P , which in turns shows that the police dataset contains more noise than the hospital dataset.

4. Discussion and Conclusions

This study computed the total number of road crash injuries with the capture-recapture method, and then estimated the likelihood that a road crash injury reported to the hospital will be reported also to the police, and vice versa.

The total number of road crash injuries in Funen in the study period is estimated to be 4-6 times higher than the number reported in the hospital and police records. The highest under-reporting rates were registered among cyclists and motorcyclists, in line with recent studies (Yannis et al., 2014; Watson et al., 2015), and in bus-related crashes. Expectedly, reporting rates increase with injury severity.

While the capture-recapture method is currently the best-practice approach to under-reporting estimation, results should be taken with caution. Model estimates reveal heterogeneity in the likelihood of reporting with respect to injury type, injury severity, road user, individual characteristics, and crash location. The likelihood of finding hospital records in police records is greater for: (i) children and adolescents under 18 years old; (ii) females; (iii) severe and fatal injuries, (iv) pedestrians, mortorcyclists and van occupants; (v) head, thorax and spine injuries; (vi) recorded seat-belt or helmet use; (vii) morning peak hours and summer time. The likelihood of finding police records in hospital records is greater for: (i) children and adolescents under 18 years old; (ii) females; (iii) severe and fatal injuries; (iv) pedestrians and van occupants; (v) recorded seat-belt or helmet use; (vi) involvement of other parties; (vii) roads with high speed limits and multiple lanes; (viii) morning peak hours and weekdays. The model estimates for the scale factors reveal that the police dataset contains more noise than the hospital dataset, and in general the loss of information in the police records confirms that road safety analysis relying on police data might be biased (e.g., Farmer, 2003; Abay, 2015).

The estimation results from the model analysing not only under-reporting to the hospital, but also under-reporting to the police, suggest a dependence of the police and hospital records in the case of severe injuries, injuries affecting consciousness and movements, and injuries that occur on high-speed multi-lane roads, which require inviting various emergency forces to the crash scene. Model estimation results also show heterogeneity in the injury reporting to both the police and the hospitals because of the road user individual characteristics, thus not only because of the road user type and injury severity outcome. These results confirm and extend previous findings (e.g. Amoros et al., 2007; Watson et al., 2015), and allow agreeing with the conclusion that "injured people are not goldfish" (Jarvis et al., 2000), namely that dependence and heterogeneity need to be accommodated in the estimation of the phenomenon of under-reporting.

A limitation of the study, and in general of police and hospital records, is that while the model estimates reveal that the reporting to the police and the hospital can be explained by individual characteristics, the data lack information about the reasons for under-reporting. Further research efforts should be directed to investigating the

behavioural reasons for under-reporting to a specific authority by focusing on behavioural theories and service management approaches.

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PAPER 2

Unravelling the relationship between trauma types and traffic crash characteristics: an error component logit approach

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Abstract

On-site decisions regarding the identification of critical injuries have an important role in the survival rate of people injured in road crashes. This study focuses on modelling the probability of a wide range of injury types with crash, vehicle and person's characteristics, with separate analysis for car occupants and VRUs. The considered injury types are combinations of primary and secondary injuries occurring in the following body parts: head, neck, thorax, spine, upper extremities, lower extremities and other. The employed model is the mixed-logit model due to its ability to represent heteroscedasticity and cross-nested correlations across combinations of injury types. Police and hospital data on from Funen, Denmark, during the years 2002 to 2008, serves for the analysis. Results show that injury types, and in particular severe injuries such as head-neck, spine and thorax, are associated with safety gear use, crash configuration, infrastructure characteristics, environmental and light conditions, in addition to individual characteristics.

Keywords: injury type, trauma type; hospital and police data; emergency care; mixed logit.

1. Introduction

Pre-hospital care has an important role in the survival rate of people injured in road crashes. An important factor is the immediacy of emergency care. Shorter distance from the crash scene to a hospital and shorter medical response time are associated with a significant reduction in crash severity and the probability of fatalities (Prato et al., 2014; Sánchez-Mangas et al., 2010). Another important factor is on-site decision-making faced by police, medical and rescue teams at the crash scene, involving decisions regarding crash severity assessment, identification of critical injuries at the crash scene, treatment prioritization in case of multiple victims, intervention type, and rescue/evacuation methods (e.g., Reyero Díez et al., 2012). On-site emergency care is inherently complex and involves a high degree of uncertainty and risk due to the high level of trauma severity, a lack of trauma information, time pressure, and the naturalistic and dynamic environment (Hagiwara et al., 2013). While pre-hospital care decisions are typically executed based on guidelines and protocols and personnel experience, judgement errors are dominant risk factors in patient survival rates (Hagiwara et al., 2013). Therefore, there is a need for research-based decision support tools that can be useful for emergency units in gaining further insights related to the linkage between crash characteristics, trauma type and severity (Reyero Díez et al., 2012).

While an ample body of research focuses on the relationship between injury severity and crash characteristics, studies linking to the occurrence of injury type to crash characteristics and configuration are scarce (Lai et al., 2012). A possible reason for the scarcity of such research is the need, in most countries, to link hospital data about trauma type with police data about crash characteristics in order to perform the analysis. The main difficulties in using the two data sources are under-reporting rates in both data sources, establishing reliable linkage between police and hospital records limited personal information without unique identifiers, and reporting discrepancies between data sources, for example with respect to crash injury severity (Rosman, 2001; Sciortino et al., 2005; Lai et al., 2006; Wilson et al., 2012). Newly developed databases in the United States and Australia allow sufficient medical and crash information to conduct such an analysis, allowing to overcome the difficulties associated with linking police and hospital data, although the difficulties associated with under-reporting remain. Examples are the studies of O'Connor and Brown (2006), Lai et al (2012), and Weaver et al. (2013) that show that the probability of certain injury types can be associated with specific crash characteristics. O'Connor and Brown (2006) linked spinal cord injury risk to crash characteristics such as vehicle type, crash type and number of vehicles involved by using the Australian Spinal Cord Injury Register (ASCIR). Lai et al (2012) associated thoracic injuries to crash, occupant and vehicle characteristics by using the National Automotive Sampling System-Crashworthiness Data System (NASS-CDS). Weaver et al. (2013) associated pulmonary contusion and its correlation to crash characteristics by using the Crash Injury Research and Engineering Network (CIREN) database. Notably, these studies focused on the risk probability of a single injury type given crash and occupant characteristics,

while disregarding the probability of other injury types under similar circumstances. Moreover, these studies focused exclusively on car occupants, while neglecting vulnerable road users (VRUs).

This study focuses on modelling the probability of a wide range of injury types with crash, vehicle and person's characteristics, with separate analysis for car occupants and VRUs. The considered injury types are combinations of primary and secondary injuries occurring in the following body parts: head, neck, thorax, spine, upper extremities, lower extremities and other. The employed model is the mixed-logit model due to its ability to accommodate a cross-nested error structure for representing correlations across combinations of injury types, as well as heteroscedasticity. Data for the analysis are retrieved police and emergency rooms on the island of Funen in Denmark during the years 2002 to 2008. The Danish Bureau of Statistic links the two data sets via pseudo civil registration numbers as unique identifiers, thus avoiding the pitfalls associated with traditional linking methods such as matching names or a set of individual characteristics. While the problem of under-reporting remains unresolved, the current study serves as a case study providing the first overview of the linkage between the occurrence probability of injury type combinations and crash, vehicle and person characteristics.

The remainder of the paper is organized as follows. Section 2 presents the data and describes the variables used in the analysis. Section 3 presents the mixed-logit model. Section 4 presents the estimation results of the two mixed-logit models for car occupants and VRUs. Last, section 5 offers a discussion and concluding remarks.

2. Data

During the years 2002-2008, 34,921 road users reported their involvement in a road crash to the police or the emergency room in Funen, of whom 15,745 reported to the police and 25,283 reported to emergency rooms. Of these road users, 6,107 (17.5%) reported both to the police and the emergency room. Police records were extracted from the Danish national crash database maintained by the Danish Road Directorate that is composed of accident, person and vehicle files. The accident file reports details concerning accident type, week day and time of day, level of severity, manner of collision, involved vehicles and road users, infrastructure characteristics, land use type, light and weather conditions. The person file provides information about each person involved in the accident, including demographics, alcohol or drug intoxication, seatbelt or helmet use, license validity and injury severity. The vehicle file contains information about each vehicle involved such as make and model, manoeuvre prior to the accident, weight, registration date, and collision point. The data registered by the emergency rooms in Funen were collected from three hospitals covering the entire region of Funen. The data contains abbreviated injury scale (AIS) with diagnostic codes related to trauma type, a limited number of crash characteristics (i.e., number of vehicles involved, the involvement of vulnerable road users and crash location), and patient information (i.e. age, and gender). The diagnostic codes for injury type differentiate injuries by body parts: head and neck, thorax, upper extremity, lower extremity and

spine. Undefined injuries are listed as other injuries. The Danish Bureau of Statistics connects the two data sets via a pseudo civil registration number of the injured person involved in the crash as a unique but anonymous identifier. The use of individual civil registration number allows the accurate matching of the two data sources without risk of false positive identification of similar crashes as identical crashes, while also avoiding coding errors that lead to false negative identification.

3. Method

The present study formulates a mixed logit model specification (McFadden & Train, 2000) to represent the probability of sustained injury types. The alternatives consist of combinations of primary and secondary injury type, e.g., head-neck as the primary injury type and upper extremity as the secondary injury type. The mixed logit model specification is formulated in order to allow investigating the existence of cross-nested similarities across alternatives, as intuitively injury types that have the same primary or the same secondary injury type could be correlated. The model also allows testing for heteroscedasticity, as the error terms related to the various injury types could be characterized by different variance.

Conditional on values for the alternative specific constants α_i and the error components μ_h, the probability of driver n sustaining injury type i is formulated according to the well-known multinomial logit model:

$$P_{in} = \frac{\exp\left(\alpha_i + \sum_{k=1}^{K} \beta_k X_{ikn} + \sum_{h=1}^{H} \mu_h\right)}{\sum_{j=1}^{J} \exp\left(\alpha_j + \sum_{k=1}^{K} \beta_k X_{jkn} + \sum_{h=1}^{H} \mu_h d_{jh}\right)} \quad (1)$$

where α_i is the alternative specific constant for injury type i, β_{ik} are parameters of K crash and driver attributes to be estimated for each alternative i, μ_h are error component parameters to be estimated for representing cross-nested similarities across alternatives, X_{ikn} are values of K crash and driver attributes associated to each alternative i for driver n, and d_{ih} are indicators of H nests that are equal to unity if alternative i belongs to nest h and zero otherwise. The error terms in the model are independently and identically distributed Gumbel errors ε_{in}.

In the present study, the alternative specific constants α_i are assumed to be distributed according to a normal distribution that allows expressing heteroscedasticity across the alternatives, and the error components μ_h are assumed to be distributed according to a normal distribution with zero mean that allows representing similarity across the alternatives. For model identification purposes, alternative specific constants are formulated as $\alpha_i \sim N(\mu_i,\sigma_i^2)$, where μ_i is the mean and σ_i^2 is the variance of the normal distribution of each constant. For cross-nesting correlation purposes, nests are formulated for injury types as $\mu_h \sim N(0,\sigma_h^2)$, where σ_h^2 is the variance of the normal distribution of the error components. Accordingly, the probability of driver n sustaining injury type i may be integrated over the distributions $f(\alpha_i)$ and $f(\mu_h)$ of the random parameters:

$$P_{in} = \int \left[\frac{\exp\left(\alpha_i + \sum_{k=1}^{K} \beta_k X_{ikn} + \sum_{h=1}^{H} \mu_h\right)}{\sum_{j=1}^{J} \exp\left(\alpha_j + \sum_{k=1}^{K} \beta_k X_{jkn} + \sum_{h=1}^{H} \mu_h d_{jh}\right)} \right] f(\alpha_i)\, f(\mu_h)\, d\alpha_i d\mu_h \qquad (2)$$

The probability does not have a closed-form expression because of the multi-dimensional integral, and hence the maximization of the likelihood function for parameter estimation requires simulation that consists in maximizing the following expression:

$$SLL = \sum_{n=1}^{N} \sum_{i=1}^{J} d_{in} \ln \left\{ \frac{1}{R} \sum_{r=1}^{R} \left[\frac{\exp\left(\alpha_i^r + \sum_{k=1}^{K} \beta_k X_{ikn} + \sum_{h=1}^{H} \mu_h^r d_{ih}\right)}{\sum_{j=1}^{J} \exp\left(\alpha_j^r + \sum_{k=1}^{K} \beta_k X_{jkn} + \sum_{h=1}^{H} \mu_h^r d_{jh}\right)} \right] \right\} \qquad (3)$$

where SLL is the simulated log-likelihood, N is the number of drivers, d_{ni} is equal to 1 if driver n sustained injury type i and 0 otherwise, r is one of the R random draws required for integral simulation, and the superscript r represents the instance of a draw of the constants α_i and the error components μ_h.

The parameters α_i, σ_i, μ_h, and β_k are estimated in the present study by using 500 random draws with a Modified Latin Hypercube Sampling (MLHS) method (Hess et al., 2006). The freeware software BIOGEME (Bierlaire, 2008) is used for model estimation thanks to its simplicity and versatility in specifying the model formulated for this analysis.

4. Results

4.1 Car occupants

Table 1 presents the car occupant injury model estimation results for variables with at least one significant category at the 0.05 significance level. The reference injury category is lower extremity injuries. The adjusted McFadden's *r*-squared is 0.154. Correlations exist across alternatives that involve the lower or upper extremities.

4.1.1 Car occupant characteristics

Relatively to females, males are more likely to sustain "upper extremity" injuries. Relatively to young adults, older car occupants are more likely to sustain thoracic injuries. 55-64 year-olds are more likely to sustain "head-neck and thorax" and "thorax" injuries. 65-74 year-old car occupants are more likely to sustain "head-neck and upper extremity", "thorax" and "thorax and spine" and are less likely to sustain "head-neck and lower extremity" injuries. Car occupants over 74 years of age are more likely to sustain "thorax" injuries.

Compared to rear passengers, drivers are more likely to sustain "head-neck", "thorax" and "other" injuries, and front passengers are more likely to sustain "spine" injuries. Car occupants who wear seatbelts are less likely to sustain spinal injuries, in particular

"head-neck and spine", "thorax and spine" and "spine" injuries. Intoxicated car occupants are more likely to sustain "head-neck" injuries.

Table 1: Mixed-logit model estimation results for car occupants injuries

		Head and Neck	Head neck and Thorax	Head, neck and lower ex.	Head, neck and upper ex.	Head, neck and spine	Thorax	Thorax and lower ex.	Thorax and upper ex.	Thorax and spine	Lower ex and upper ex.	Lower ex and spine	Upper extremity	Upper ex and spine	Spine	Other
	Constants	1.20	0.35	-0.88	-0.35	1.27	1.21	-2.40	-2.67	0.68	-1.72	-0.31	-0.38	-1.57	1.12	-1.50
Gender	Female*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Male	-	-	-	-	-	0.30	-	-	-	-	-	0.50	-	-	-
Age	0-9 years old	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	10-14 years old	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.94	-
	15-17 years old	-	-	-	-	-	-	-	-	-1.15	-	-	-	-	-	-1.53
	18-24 years old	-	-	-	-	-	-	-	-	-0.74	-	-	-	-	-	-
	25-34 years old*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	35-44 years old	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	45-54 years old	-	-	-0.52	-	-0.76	-	0.73	-	-	-0.87	-	-	-1.03	-	-
	55-64 years old	-	1.08	-	-	-	0.91	-	-	-	-	-	-	-	-	-
	65-74 years old	-	-	-1.99	0.87	-	1.39	-	-	1.36	-	-	-	-	-	-
	Over 74 years old	-	-	-1.76	-	-	1.70	-	-	0.84	-	-	-	-	-	-
Seatbelt	Yes	-	-	0.52	-	-0.73	-	0.99	-	-0.76	-	-	-	-	-0.81	-
	No*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Alcohol Drugs	Yes	0.57	-	-	-	-	-	-	-	0.64	-	-	-	-	-	-
	No*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Seat	Driver	0.41	-	-	-	-	0.64	-	-	-	-	-	-	-	-	1.54
	Front Passenger	-	-	-	-	-	-	-	-	-	-	-	-	-	0.35	-
	Rear passenger*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Accident Type	Single vehicle	-	-	-	-	-	-	-	-	-0.51	-	-	-	-	-	-0.82
	Same direction	-	-1.18	-	-0.81	-1.03	-	-	-2.62	-1.52	-0.87	-1.23	-1.49	-1.92	-1.07	-1.16
	Opposite direction	-	-0.80	-	-	-	-	-	-	-	-	-	-	-	-	-
	Intersection (turn)	-	-1.26	-	-0.75	-1.13	-	-	-	-0.84	-	-1.32	-	-0.88	-1.19	-0.64
	Intersection (straight)	-	-0.70	-	-	-0.80	-	-	-	-0.60	-	-0.95	-	-0.92	-0.87	-0.69
	Parked vehicle *	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Pedestrian accident	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Object/Animal/train	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Speed limit	0-60 km/t*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	70-90 km/t	-	-0.64	-	-	0.66	-	-	0.93	0.68	-	0.46	-	0.98	0.71	0.74
	100-130 km/t	-	-	-	-	1.72	-	-	2.19	1.06	-	1.03	0.95	2.23	0.88	-
Lanes	One	-	0.82	-	-2.01	-1.14	-	-	-	-	-	-1.83	-	-	-	-
	Two*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Three or more	-	-	0.44	-	-	-	-	-	-	-	-	-	-	-	-
	Other	-	-	-	-	-	-	-	-	0.70	-	-	0.57	-	-	-
Illumined roads	Yes	-	-	-	-	0.46	-	-	0.67	0.50	-	0.58	-	-	-	-
	No*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Clear sight	Yes	-	-	-	-	-	-	-	-	-	-	-	-	-	0.99	-
	No*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Slippery roads	Yes	-	-	-	-	-	-	-	-	-	-	-0.47	-	-	-	-
	No*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Weekend	Yes	0.38	-	-	-	-	0.47	-	-	-	-	-	-	-	-	-
	No*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Time of Day	6.01-9.00	-0.53	-0.72	-	-	-0.61	-0.46	-0.72	-	-	-	-	-0.61	-	-0.85	-1.62
	9.01-15.00*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	15.01-18.00	-	-0.50	-	-	-0.55	0.41	-1.06	-	-0.75	-	-	-	-	-	-
	18.01-21.00	-	-	-	-	-	-	-	-	-	-	-	-0.69	-	-	-
	21.01-6.00	-	-0.93	-	-0.57	-	-	-	-	-	-	-	-	0.83	-	-
Season	Summer*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Autumn	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Winter	-	-	-	-	-	-	-	-	-0.42	-	-	-	-	-	-
	Spring	-	-	-	-	0.27	-0.45	-	-	-	-	-	-	-	-	-

Note: * - base category, green shading – significant at the 0.05 significance level, blue shading – significant at the 0.2 significance level, red shading – significant at lower significance level.

4.1.2. Crash configuration and infrastructure characteristics

Car occupants involved in crashes that occur at intersections have a lower likelihood to sustain injuries related to head-neck and spine as primary injuries. In particular, the probability is lower for “head-neck and thorax”, “head-neck and spine”, “spine” and “lower extremities and spine”. In the case of turning vehicles, the likelihood is even lower than for vehicles going straight, and there is also lower probability to sustain injuries of type “head-neck and upper extremity” and “lower-extremity and spine” injuries. Car occupants involved in crashes between two vehicles going in the same direction are less likely to sustain most of the injury types, apart from injuries related to the combinations of head-neck or thorax with lower extremity.

Compared to car occupants injured in crashes that occurred on roads with low speed limits (60 km/h), car occupants injured on roads with speed limits of 70 km/h or higher have a higher probability of sustaining injuries related to the spine, i.e., “spine”, “upper extremity and spine”, “thorax and spine” and “head-neck and spine”. Injuries related to “upper extremity” and “thorax and upper extremity” are also more likely when the speed limits are higher. Notably, the probability to sustain all of these injury types is higher for crashes that occurred on roads with speed limits above 90 km/h.

Compared to two-lane roads, car occupants injured on one lane roads are more likely to sustain “head-neck and thorax” injuries and are less likely to suffer from the combination of head-neck with spine or upper extremity injuries. In roads with three lanes or more, “head-neck and lower extremity” injuries have a higher likelihood.

4.1.3 Environment and light conditions

Regarding car occupant injuries, among the environmental conditions, time of day is the most prominent factor.

Compared with off-peak hours (09:00-15:00), occupants that are injured in crashes during morning peak-hour are less likely to suffer from “head-neck”, “head-neck and spine”, “spine”, “upper extremity” and “other” injuries. Crashes that occur during early evening are associated with a lower probability of “upper extremity” injuries, and crashes that occur during late evening and night are associated with a higher probability of “upper extremity and spine” injuries and a lower probability of “head-neck and thorax” injuries.

Road illumination is associated with a higher probability of “head-neck and spine” injuries. Car occupants involved in crashes on weekends have a higher likelihood of “head and neck” and “thorax” injuries. Spring is associated with a lower likelihood of “thorax” injuries, and slippery roads are associated with a lower probability of “lower extremity and spin” injuries.

4.2 Vulnerable road users

Table 2 presents the VRU injuries model estimation results for variables with at least one significant category at the 0.05 significance level. The reference injury category is

lower extremity injuries. The adjusted McFadden's r-squared is 0.149. For the VRU model, the correlations across alternatives resulted insignificant.

Table 2: Mixed-logit model estimation results for VRU injuries

		Head and Neck	Head, neck and Thorax	Head, neck and lower ex.	Head, neck and upper ex.	Head, neck and spine	Thorax and lower ex.	Thorax and spine	Lower and upper ex.	Lower ex and spine	Upper extremity	Upper ex and spine	Spine	Other
	Constants	-0.878	-3.969	-0.521	-0.705	-1.040	-0.696	-2.85	-1.136	-2.26	-0.316	-2.11	-0.311	0.044
Road user	Pedestrian*													
	VRU wearing helmets	-0.564							0.606		0.419			0.585
	Cyclist without helmet	0.535	1.260	0.981	1.179	1.103			0.567		0.851	-1.125	0.436	0.691
	Moped without helmet					1.384							0.889	0.844
	Motorcyclist without helmet													
Gender	Female*													
	Male					0.346		0.993					0.258	0.374
Age	0-9 years old	1.311		1.081						1.455				
	10-14 years old													
	15-17 years old						-1.076							
	18-24 years old			0.379		-0.575								
	25-34 years old*													
	35-44 years old											0.8559		
	45-54 years old					0.3747								
	55-64 years old	0.492								0.454				
	65-74 years old													
	75 years old or more										-0.6614			
Accident type	Single vehicle*													
	Same direction									0.503			-0.801	-1.111
	Opposite direction					-1.067								-0.951
	Intersection (turn)			-0.426		-1.784		-1.146	-0.6204		-0.693		-1.233	-1.465
	Intersection (straight)				0.4223	-1.025				0.490	-0.529			-1.251
	Crash with parked vehicle	1.464			0.701									
	Pedestrian accident													
	Object/Animal/train													
	Only VRU					-0.508							-0.398	-0.827
Other party	Pedestrian													
	Cyclist													
	Moped	0.824									-1.011		-1.675	-0.811
	Motorcyclist									1.121				
	Car*													
	Van													
	Truck													
	Bus													
Speed limit	0-50 km/t*													
	70-90 km/t									0.941			0.854	
	100-130 km/t													
Lanes	One										-0.728			
	Two*													
	Three or more								0.431		0.343			-0.714
	Other													
Clear sight	Yes			-1.270	-1.229		-1.483							
	No*													
Slippery roads	Yes				-0.550	0.305								
	No*													
Weekend	Yes				-0.402									-0.335
	No*													
Time of Day	6.01-9.00										-0.4932			
	9.01-15.00*													
	15.01-18.00													
	18.01-21.00				0.637							0.923	0.272	
	21.01-6.00	0.594			0.910				-0.540	0.675				
Season	Summer*													
	Autumn									-0.3425	-0.344	-0.606		0.323
	Winter										-0.484	-1.053	-0.560	
	Spring								-0.331	0.520				

Note: * - base category, green shading – significant at the 0.05 significance level, blue shading – significant at the 0.2 significance level, red shading – significant at lower significance level.

4.2.1 VRU characteristics

Compared to pedestrians, VRU wearing helmets are less likely to sustain “head-neck” injuries and are more likely to sustain “lower and upper extremity”, “upper extremity” and “other injuries”. Compared to pedestrians and VRU wearing helmets, cyclists who do not wear helmets are associated with a higher probability of sustaining spine, upper extremity and head injuries, with the three most probable injuries being “head-neck and thorax”, “head-neck and upper extremity” and “head-neck and spine”. Motorcyclists who do not wear helmets are more likely to sustain spine injuries, with a higher probability to “head-neck and spine” and “spine” injuries.

With respect to females, males are more likely to sustain “thorax and spine” and other injuries. Compared to all other age groups, children up to nine years old are much more likely to sustain “lower extremity and spine” injuries, “head-neck” and “head-neck and “lower extremities” than all other injury type. 35-44 year-old adults are more likely to sustain injuries in the “upper extremity and spine”, and 55-64 year-old adults are more likely to sustain “head-neck” injuries.

4.2.2. Crash configuration and infrastructure characteristics

Compared with other crash types, VRUs injured in crashes involving a vehicle at intersections have a much lower probability of sustaining “head-neck and spin, “upper extremity” and “other” injuries. In case that the vehicle at the intersection is in turning movement, other injury types with lower probability are “lower and upper extremity” and “spine”. Crashes involving a parked vehicle and a VRU have a much higher likelihood of “head-neck” injuries than other crash types. VRUs involved in crashes alone, with a vehicle going straight at road sections, or with vehicle at intersections have a lower likelihood of sustaining “other injuries” relatively to other crash types.

Compared with crashes that occur on two-lane roads, VRUs involved in one-lane roads are less likely to sustain “upper extremity” injuries, and VRUs involved crashes that occur in multi-lane roads are less likely to sustain “other” injuries.

Compared to crashes occurring on road with speed limits of up to 60 km/hr, crashes occurring on roads with 70-90 km/hr speed limits are associated with higher likelihood to sustaining spine injuries, in particular “spine and lower extremities” and “spine”.

4.2.3 Vehicle characteristics

Compared to crashes with other road users, crashes that involve a VRU and a motorcyclists as another VRU are associated with a higher probability of “lower extremity and spine” injuries. Crashes involving a moped as the collision partner have a higher likelihood of “head and neck” injuries and a lower likelihood of “spine” injuries.

4.2.4 Environment and light conditions

VRUs involved in crashes during the evening or at night have a higher likelihood of sustaining injuries involving the head or the spine, particularly “head-neck and upper extremity”, “head-neck”, “upper extremity and spine” and “lower extremity and spine” injuries. VRUs involved in crashes during morning peak-hours are less likely to sustain “upper extremity” injuries.

VRUs involved in crashes in places with a clear line of sight are less likely to result in injuries involving “head-neck and upper extremities” and “head-neck and lower extremities”.

Injuries that occur on slippery roads are less likely to be of type “head-neck and upper extremities”. Seasonal effects are mostly associated with “lower extremity”, “upper extremity”, “spine” and “other” injuries. During winter and autumn injuries of types “spine”, upper extremity and spine” and “upper extremity” are less likely. During autumn, “other” injuries are more likely and during spring “lower extremity and spine” are more likely.

5. Conclusions

The current study focuses on modelling the probability of road users suffering different types of injuries as a function of crash, vehicle and person’s characteristics, while performing the analysis separately for car occupants and VRUs. The considered injury types are combinations of primary and secondary injuries occurring in the following body parts: head, neck, thorax, spine, upper extremities, lower extremities and other. The data comprise police and hospital records collected in Funen, Denmark, during the years 2002 to 2008, while the model is a mixed-logit model due to its ability to account for heteroscedasticity in the injury outcomes and the correlation across injury types.

Results show that injury types are related to the use of safety gear such as seat belts and helmets, the configuration of the crash, the characteristics of the environment and the light conditions, in addition to characteristics of the road users such as gender and age. In particular, results highlight that injuries to head-neck, spine and thorax relate to the crash and individual characteristics, an interesting finding when considering that these are the body parts with the potentially most severe consequences when injured. Results are interesting when considering that the decision making on crash sites relates nowadays to guidelines and protocols based on experience, while findings from this study suggest how to develop a DSS system that could be complementary to the guidelines currently in operation today. For example, the findings suggest the correlation of specific injury types with specific crash configurations, and could suggest which type of intervention prioritize if a priority scale of body parts is considered. Moreover, findings from this study suggest how safety gear is very helpful to prevent critical injury types, thus have extensive potential in reducing the most severe consequences by reducing injuries to head-neck, spine and thorax.

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PAPER 3

The choice to report cycling crashes to the police and hospitals in Denmark: the role of attitudes, norms and perceived difficulties

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Abstract

This study explores the behavioural factors underlying the reporting intentions of cycling accidents. The proposed analytical framework is an adapted version of the Theory of Planned Behaviour accounting for the linkage between attitudes and perceived difficulties, in order to understand the barriers impeding cycling accident reporting intentions. The barriers consist of attitudes that accident reporting is useless, preference to allocate time to other activities, concerns about family distress and social image, distrust in the police, and medical consultation aversion. The framework was validated by means of a survey, which yielded 1,512 complete responses from cyclists, and a structural equation model. Estimates of the models revealed that: (i) the perceived difficulties are related to the reporting intentions, the attitudes that accident reporting is useless, and the preference to allocate time to other activities; (ii) the medical consultation aversion has a higher weight than the distrust in the police in demotivating cycling accident reporting intentions; (iii) the latent factors are mainly related to socio-economic characteristics and last cycling accident characteristics; (iv) information provision regarding the societal benefits of accident reporting is important for increasing the reporting rate.

Keywords: accident under-reporting; cycling accidents; Theory of Planned Behaviour; cognitive dissonance; structural equation models.

1. Introduction

Encouraging people to cycle is one of the main public health challenges of the modern era because it carries both advantages and concerns. The advantages involve the physical activity that helps maintaining body shape and preventing heart diseases, while the concerns regard the exposure to traffic pollution and accident risk. Considering that the fear of cycling accidents is the most significant disincentive to cycling, investigating the risk factors underlying cycling accidents is fundamental for increasing the appeal of cities and regions to potential cyclists.

National statistics are often used to identify the factors underlying cycling accident frequency and severity, and several studies used these statistics to provide insights regarding the effects of accident location, presence of cycling facilities, traffic conditions and cyclist characteristics. From the location perspective, intersections (e.g., Wang & Nihan, 2004; Dumbaugh & Rae, 2009) and roundabouts (e.g., Hels & Orozova-Bekkevold, 2007; Møller & Hels, 2008) were found to contribute to higher accident rates, while signalized intersections were related to a higher likelihood of severe and fatal injuries to cyclists (Reynolds et al., 2009) although in general intersections were linked to reduced injury severity (Kaplan et al., 2014). From the infrastructure perspective, the presence of cycling facilities was related to an increase in the accident rates of cyclists (e.g., Aultmann-Hall & Hall, 1998; Pucher et al., 1999), although recent evidence contradicted these initial findings and proclaimed bicycle lanes as safer (De Rome et al., 2014; Kaplan et al., 2014; Kaplan & Prato, 2015). Moreover, higher numbers of light injuries among cyclists were recorded in proximity of parking facilities and public transport stops (e.g., Kim et al., 2007; Rifaat et al., 2011; Kim and Kim, 2014). From the traffic condition perspective, both peak and off-peak hours were shown to have less accidents (e.g., Wang & Nihan, 2004; Hels & Orozova-Bekkevold, 2007), but the severity was found lower in peak hours because of the reduced speed differential between fast and slow transport modes and higher in off-peak hours because of high vehicle speeds (e.g., Klop & Khattak, 1999; Kim et al., 2007; Kaplan et al., 2014). From the individual perspective, cyclists' fragility and intoxication level were linked to more severe injury outcomes among cyclists (Kaplan et al., 2014), and maneuver types and vehicles involved were shown to play a role in the severity outcomes (Bil et al., 2010; Hu et al., 2013; Kaplan et al., 2014). Yet, national statistics are well-known to suffer from severe under-reporting, particularly for accidents involving cyclists. In order to overcome this limitation, the analysis is often limited to bicycle accidents with motorized vehicles, which are more likely to be interested in determining fault for insurance claim purposes, and is generally excluding single cyclists falling or colliding against another vulnerable road user or a fixed object, although they can also result in serious injuries (see, e.g., Kaplan et al., 2014; Weber et al., 2014; Kaplan & Prato, 2015).

The under-reporting of non-fatal casualties is well documented, particularly for accidents involving cyclists (Aptel et al., 1999; Amoros et al., 2007). Recent studies focused on the magnitude of the phenomenon, namely on the estimation of the under-

reporting rate of cycling accidents in various countries by using the capture-recapture method. In New-Zealand the estimated completeness of cycling accidents in the national statistics was about 74% (Tin Tin et al., 2013). In León (Nicaragua), only about 3% of the cycling accidents reported to hospitals were recorded by the police (Tercero & Andersson, 2004). In La Réunion and the Rhône region (France), only 16% and 20% of hospital cycling accident records had respectively a matching police record (Aptel et al., 1999; Amoros et al., 2007). In Switzerland it was suggested that while all the fatal cycling accidents are reported, only 25% of the severe bicycle injuries, 15% of the slight injuries and 3% of the very slight cycling injuries are reported (Aptel et al., 1999). In Denmark, 17,500 cyclists seek medical care at hospitals every year, but only 10% of the cyclist accidents reported to the hospital have been recorded in the official accident data collected by the police (Elvik & Mysen, 1999), and the under-reporting rate is even lower for light injuries and solo cyclist accidents (Kaplan et al., 2014). An important knowledge gap in the literature regarding under-reporting of traffic accidents in general, and bicycle accidents in particular, is that very little is known regarding the human factors and social conditions underlying cyclists' choice to report accidents in which they are involved. Recent studies provided evidence that under-reporting is not randomly distributed across accidents, but suffers from selection bias. In France, under-reporting was found to vary by accident severity, urban or rural location, road user type, police control area and third-party involvement (Amoros et al., 2007). The reasons stated by people who did not report their accidents suggest that reporting usefulness and police distrust play a role in under-reporting (Amoros et al., 2007). Nevertheless, the relationship between the choice to report a accident and human and social factors has never been systematically explored.

The current study is the first to explore the factors associated with the intentions to report an accident to the police and/or hospital, with a particular focus on cyclists in Denmark. Understanding the socio-economic background, personal attitudes, social norms and perceived difficulties related to the choice of road users to report cycling accidents can help in designing policy measures aimed at gaining information about road safety hazards by increasing the overall reporting rates while reducing the under-reporting bias associated with crash location and characteristics. Eventually, the substantial information gain will lead to better accident and injury analysis and prevention, and the encouragement of incident reporting will align to the new road safety approach consisting of the combination of planning forgiving infrastructure alongside encouraging safe, aware, alert, consistent and compliant behavior through enhancing safety culture and the sense of shared responsibility (Danish Road Safety Commission, 2011; Hughes et al., 2015). Creating a road-user focused environment, which is open to feedback (including incident reporting) and is successful and emphatic in handling road user needs, is crucial in the construction of such a system. In fact, the medical literature has recently proven that incident reporting is related to an improvement in the perception of 11 out of 13 safety culture aspects (Volz et al., 2010). The maritime transport literature has shown that incident reporting creates positive safety attitudes and increases alertness, and a positive relationship exists between a higher assessment of the safety climate and a higher level of incident reporting

(Kongsvik et al., 2012). Besides the extremely low reporting rates of cycling accidents, particularly in the case of light injuries and solo accidents (Kaplan et al., 2014), the current studies focuses on accident reporting by cyclists because of the high number of near-miss incidents experienced regularly by cyclists, around 0.7-0.9 incidents per day cycled (Joshi et al., 2001), and the resulting emotional stress that leads to cycling avoidance (Kaplan & Prato, 2014).

The behavioural framework proposed for the analysis is Ajzen's (1991) Theory of Planned Behaviour (TPB), which has been adapted to the research context of under-reporting cycling accidents. Since there is currently no information regarding the underlying reasons for the under-reporting of traffic accidents in general, and cycling accidents in particular, the proposed behavioural framework is based on the under-reporting of other types of incidents involving personal harm and material damage from other sectors. The proposed behavioural framework is the first of its kind in both the specific context of traffic accident reporting and the general context of incident reporting including work-related, maritime transport, and intentional harm incidents. The hypothesis of the framework is that cyclists' intentions to report a cycling accident/incident to the police and/or the hospital are related to their attitudes towards reporting usefulness and efficiency in terms of time management, the opinions of family and friends that shape the social norms towards reporting, and the perceived difficulties including distrust in the police and medical consultation aversion. A custom-designed web-based questionnaire was design for data collection and Structural Equation Models (SEM) were employed for modelling the cyclists' intention to report a cycling accident in the future according to the proposed behavioural framework. SEM are particularly useful in accommodating the latent nature of the attitudinal constructs as well as the observed nature of socio-economic characteristics and cycling travel patterns.

The paper is structured as follows. The next section presents the behavioural framework, the survey design and the mathematical model. Then, the results are presented and discussed. Last, conclusions and directions for further research are presented.

2. Methods

2.1 Behavioural framework

The behavioural framework was built upon the TPB (Ajzen, 1991) under the hypothesis of its usefulness for describing the underlying determinants of reporting intentions given its established support for incident reporting in other fields such as sport and health-care. While there exists some evidence of the relation between accident under-reporting, demographic variables and accident characteristics, there exists little to no information of the psychological and sociological factors underlying accident under-reporting. Notably, the problem of under-reporting is not unique to traffic accidents, but it is rather a more general problem concerning incidents involving both unintended and intended harm. Severe under-reporting of magnitude similar to traffic accidents

has been observed also for incidents involving unintended harm such as work-related accidents (e.g., Probst & Graso, 2013) and sport injuries (e.g., Westman et al., 2010; Fraas et al., 2014). Severe under-reporting has been documented also for incidents involving intended harm, namely crime reporting with or without seeking medical help (e.g., Jones et al., 2009; Kääriäinen & Siren, 2011; Leshem et al., 2015). Therefore, the current study formulated the research hypotheses on the basis of a critical review of incident reporting in critical events that involve harm to people and property damage and thus require medical examination and a formal report to the relevant authorities, with the aim of overcoming the lack of information concerning the reasons underlying traffic accident under-reporting.

The proposed behavioural framework hypothesizes that attitudes regarding the perceived personal and societal usefulness and time-related efficiency associated with accident reporting, social norms concerning the perceived family distress and social image, and perceived difficulties associated with police distrust and medical consultation aversion, form the barriers to cycling accident reporting. Two model forms of the behavioural framework are hypothesized and graphically represented in Figure 1. The first model form is the traditional TPB (Ajzen, 1991) in which attitudes, social norms and perceived behavioural control are associated independently with the reporting intentions, although they are correlated through the error terms in the mathematical formulation because of their belonging to the same individual. The second model form is inspired by the type of cognitive dissonance manifested in the technology acceptance model (Venkatesh & Davis, 2000). Cognitive dissonance makes individuals experience a feeling of stress and discomfort when they hold contradicting attitudes and behaviour, and individuals will either change their behaviour to match their attitudes or vice versa (Festinger, 1957). When the behavioural change is difficult, for example in the case of addictive behaviour and moral choices, the cognitive dissonance mitigation strategy leads to changing attitudes in order to justify the behaviour. In the technology acceptance model, attitudes towards the perceived usefulness of a technology are positively motivated by the perceived ease of use, and both are related to usage intentions (Venkatesh & Davis, 2000). Accordingly, the second model form hypothesizes that the perceived difficulties are not only demotivating factors leading to accident under-reporting, but also constructs underlying the attitudes regarding the usefulness and the efficiency of cycling accident reporting, which are formed in order to justify the non-reporting behaviour. The TPB constructs in both model forms are described in the following paragraphs.

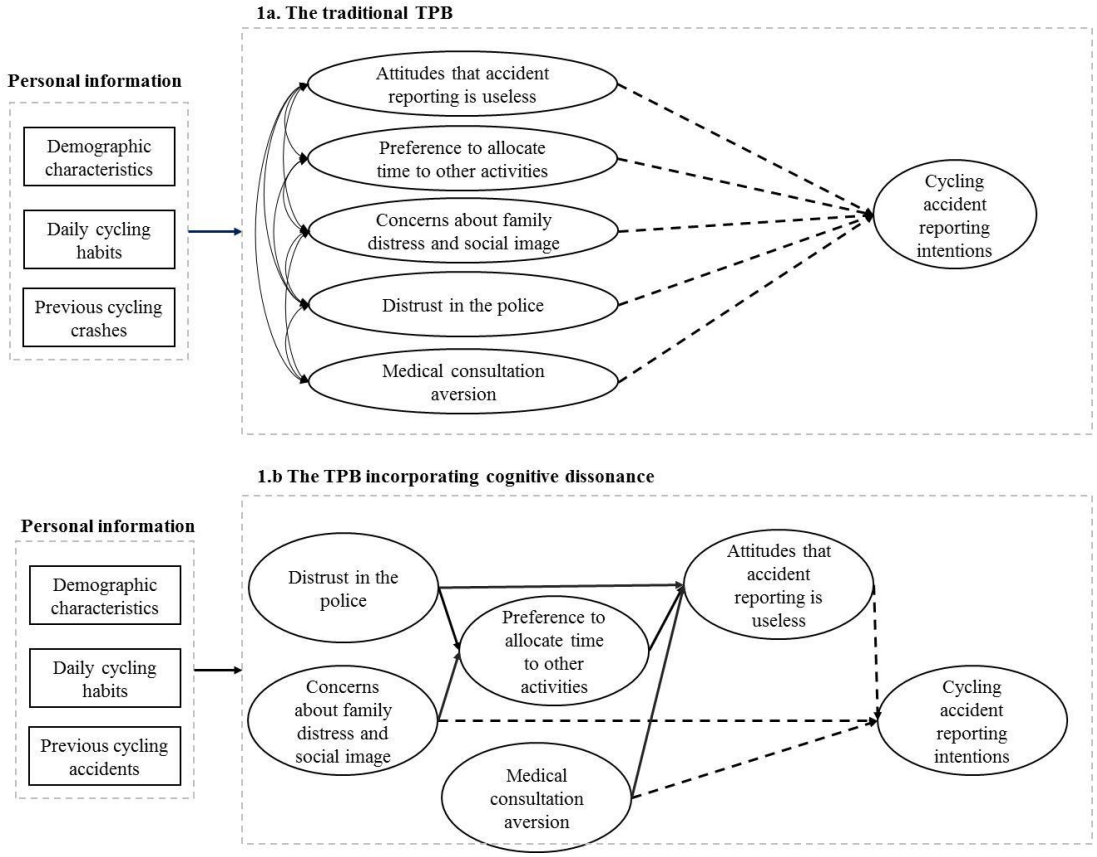

Figure 1: The behavioural framework

Attitudes regarding the usefulness of accident reporting. Anecdotal evidence shows that a possible reason for non-reporting behaviour is the perception that the report is useless because of either the non-involvement of a third-party, the reaching of an amicable agreement, or the non-occurrence of a serious injury (Amoros et al., 2007). Hence, the decision for reporting a traffic accident seems related to personal gain, for example for claiming insurance reimbursements, determining fault or resolving conflicts. Moreover, an important motivator for incident reporting in the maritime transport and health-care sectors is the belief that incident reporting is useful for organizational learning, insight contribution and safety improvement achievement (Kongsvik et al., 2012; Lindsay et al., 2012). Accordingly, the behavioural framework hypothesizes that the perceived lack of personal or societal gains forms a barrier to accident reporting.

Attitudes regarding time-related efficiency of accident reporting. Studies regarding incident reporting in the maritime transport and health-care sectors cite time constraints as major barriers to incident reporting, even in the case of severe consequences, because incident reporting systems are perceived as non-flexible, cumbersome, complex and time consuming to complete (Kongsvik et al., 2012; Lindsay et al., 2012; Williams et al., 2013; Winswold Prang & Jelsness-Jørgensen, 2014). Similarly, traffic accident reporting is also cumbersome and time consuming, as it can take several hours when considering the need to report separately to the police and the

health-care system and factoring the access, waiting and egress times at the police station and/or the health-care facility. Additionally, reporting an accident immediately after its occurrence may not be always practical or convenient due to pre-scheduled activities. Although Danish authorities are flexible in terms of the accident reporting time-frame and allow the accident reporting to occur within a "reasonable" time, the need to report in the case of damage only or light injury accidents decreases with time. Therefore, the behavioural framework hypothesizes that unwillingness to allocate time is a barrier to accident reporting.

Social norms. Norms create a projection of reality that motivates individuals' actions regardless of the factual reality and thus are an important motivator of intentions. Lack of support from family and friends, feelings of guilt and shame, fear of family distress, perceived social image, and peer-pressure, have been found to be associated with incident under-reporting in various types of incidents including sexual assault, community violence and severe sport injuries (Kroshus et al., 2015; Leshem et al., 2015). Fear of disciplinary action and embarrassment are also barriers to incident reporting in the maritime transport sector (Kongsvik et al., 2012). This happens because, while social networks can act as supportive environments, they can also transmit judgement that translates into stigma and shame (Leshem et al., 2015). Recent studies showed that traffic accident victims, both drivers and passengers, experience self-blame, guilt and family distress (Peltzer & Renner, 2004). Since it is commonly recognized that human errors play a major role in traffic accidents, the behavioural framework hypothesizes that the fear of family distress and the perceived social image are barriers to accident reporting intentions.

Distrust in the police. The behavioural framework hypothesizes that police distrust plays a role in accident reporting. Reporting an accident requires communication between individuals and the police as an institution that assumes the dual role of both service provider and authority, and consequently trust issues may manifest. Distrust in the police, interpreted as a psychological state with negative feelings towards an institution, was mentioned as a severe impeding factor to incident reporting in studies involving domestic violence and sexual assault (Jones et al., 2009). Also, institutional trust was recently associated with attitudes regarding the usefulness of e-government services (Ozkan & Kanat, 2011). Last, a recent study showed that police distrust along with high societal trust is related to low crime reporting rate (Kääriäinen & Siren, 2011). In the current study, distrust in the police is hypothesized to be related to indicators of perceived general trust in the police, perceived service courtesy and friendliness, perceived competence, reliability and effectiveness.

Medical consultation aversion. Traffic accident under-reporting is generally associated with injury severity (Amoros et al., 2007; Kaplan et al., 2014), while work-related accident reporting (especially in hospitals) is usually associated with the perceived self-efficacy, namely the ability to assess the accident severity underlies reporting intentions. Nevertheless, an individual without prior medical knowledge would be reasonably seeking medical help because driven by medical help-seeking habits rather

than self-efficacy in assessing the incident severity. This hypothesis is in line with findings from the medical literature that intentions to undergo tests for the early detection of serious illnesses are related to health system utilization and health seeking habits rather than perceived self-efficacy (O'Mahony et al., 2011). While serious injuries resulting in severe pain or moving difficulty are easily detected and assessed as requiring medical treatment, light injuries are assessed as needing medical help in relation to medical care seeking habits. In the current study, the behavioural framework hypothesizes that medical consultation aversion affects reporting intentions and, in line with the medical-help seeking scale (DiLorenzo et al., 2015), is expressed through indicators of aversion from medical examination, trust in the medical system, habitual medical consultation for various purposes, and perceived self-efficacy in assessing one's health.

The TPB constructs are hypothesized to be related to the individuals' characteristics, cycling habits, cycling accident exposure in the last 10 years, and previous reporting experience. Individuals' characteristics include gender, age, education, income, family status, residential location and its rurality degree. Cycling habits consists of weekly cycling frequency, daily cycling distance, cycling experience in years and main cycling purpose between utilitarian, recreational, or both. Cycling accident exposure comprises the number of cycling accidents and incidents in the last 10 years, as well as details of the most recent accident in terms of approximate date, time-of-day, type of road users involved, presence of friends or relatives at the scene, location with respect to residential location, nearest hospital, and nearest police station, associated health symptoms, and various reporting options (i.e., police, hospital, own medical doctor, pharmacy, emergency hotline).

3. Survey design and administration

The data for the analysis were collected via a custom-designed web-based questionnaire that was carefully designed on the basis of the literature and was divided into five parts.

Eliciting future accident reporting intentions could result in an ill-defined variable due to the uncertainty involved with future events. An option was to emulate previous studies that resolved this problem by asking about general reporting tendencies and past reporting behaviour (e.g., Probst & Graso, 2013; Fraas et al., 2014). However, concerns exist with both approaches: (i) the problem with general reporting tendencies is that they are generated on the basis of fuzzy concepts and thus may not be relevant to a particular situation; (ii) the problem with past reporting behaviour is that it may not reflect current attitudes, social norms and perceived difficulties of the individual. Another option was to use a well-specified future accident situation. However, this approach might trigger other problems such as the feeling of discomfort associated with evil-eye beliefs resulting in high non-response rate, the lack of relevance of the described situation to a large share of the respondents, and the inability to generalize the results. Accordingly, the survey design resolved this problem by engaging in a voluntary past-oriented mental time travel exercise to recall the last cycling accident as

a reference point, thus anchoring the hypothetical exercise of cycling accident reporting intentions without triggering the superstitious evil-eye belief.

The relevance of past memories for a hypothetical future situation is that hypothetical thinking involves recombining episodic memories into a representation of the future (Berntsen & Bohn, 2010). Moreover, the relevance of memories of the last cycling accident relates also to generating relevant and realistic accident situations as well as representing cycling accident heterogeneity so that the reporting intentions can be modelled as a function of accident characteristics. Therefore, the survey elicited the respondents' last cycling accident in terms of time-of-day, distance from the nearest hospital and the nearest police station, distance from the residence, health symptoms experienced, accompanying persons and collision partners. The reporting intentions of the future cycling accident were asked after the participants had to recall their last accident and to state their attitudes, norms, and difficulties, in order to enhance the clarity and realism associated with the hypothetical situation. The respondents were asked about both the willingness to report a future cycling accident provided that the reporting method may be selected (i.e., police, hospital, internet, mobile app) and that the information is used for improving cycling safety (e.g., 10 DKK, about 1.5 USD, invested in cycling infrastructure).

The individual attitudes, subjective norms, and perceived behavioural control that are barriers to reporting a cycling accident were measured on a 5-point Likert scale ranging from "strongly disagree" to "strongly agree". Due to the scarce information regarding the underlying factors of incident reporting in general, and traffic accident reporting in particular, the factor items were constructed on the basis of the available literature on incident reporting and a brainstorming process of a small focus group of cyclists including researchers and students.

The elicited cyclists' socio-economic characteristics included age, gender, income, place of residence, relationship status and having children. The elicited cycling habits included monthly cycling frequency, daily cycling distance, cycling experience in years, cycling purpose between utilitarian, recreational, or both, and cycling accident frequency.

The survey was administered in Danish via three types of on-line cyclists' social networks during September and October 2014. The first type consists of formal social networks for promoting cycling: the network of Odense - city of cyclists, and the network of the Danish Cyclist Federation. The second type consists of academic social networks in several universities all over the country since students form an important part of the cyclist population in Denmark: Technical University of Denmark, University of Copenhagen, Aalborg University, Soenderborg Gymnasium, and Roskilde University. The third type includes the professional and personal networks of transport stakeholders with an interest in cycling research: Danish Road Directorate, Danish National Police, insurance companies, municipalities, and the Danish Council for Traffic Safety. The survey administration through the third type of social networks was promoted by an official newsletter followed by personal correspondence.

4. Mathematical model

The hypothesized behavioural framework was investigated via the formulation of SEM. Specifically, the model in this study contained three sets of equations: measurement equations (eq. 1), structural equations linking the latent attitudinal constructs to the cyclists' characteristics, cycling habits and previous experience with cycling accident and reporting (eq. 2), and structural equations relating the latent attitudinal constructs to cycling accident reporting intentions (eq. 3).

$$I_{dn} = Z^*_{ln}\alpha_d + \upsilon_{dn} \quad and \quad \upsilon_n \sim N\left(0, \Sigma_\upsilon\right) \quad for\ d = 1,\ldots,D \tag{1}$$

$$Z^*_{ln} = SC_{ln}\beta_{l1} + CH_{\ln}\beta_{l2} + CA_{\ln}\beta_{l3} + \omega_{ln} \quad and \quad \omega_n \sim N\left(0, \Sigma_\omega\right) \quad for\ l = 1,\ldots,L \tag{2}$$

$$R^*_{in} = Z^*_{ln}\beta_r + \xi_{in} \quad and \quad \xi_n \sim N\left(0, \Sigma_\xi\right) \quad for\ i = 1,\ldots,I \tag{3}$$

where Z^*_{ln} is the value of latent construct l for cyclist n, I_{dn} is the value of an indicator d of the latent construct Z^*_{ln} as perceived by cyclist n, SC_{ln} is a vector of cyclists' socio-economic characteristics, CH_{ln} is a vector of cyclists' cycling habits, CA_{ln} is a vector of cyclists' accident exposure, and R_{in} is a vector of cyclists' accident reporting intentions. Error terms are expressed as elements υ_{dn}, ω_{ln}, and ξ_{in} of the vectors following a normal distribution with respective covariance matrices $\Sigma\omega$, $\Sigma\upsilon$ and $\Sigma\xi$, while parameters to be estimated are α_d, β_{l1}, β_{l2}, β_{l3}, and β_r. Considering D indicators translates into writing D measurement equations and estimating a ($D\times1$) vector α of parameters (i.e., one parameter is estimated for each equation), while considering L latent constructs translates into writing L structural equations and estimating an ($M\times L$) matrix of β parameters (i.e., M parameters are estimated for each equation).

The model was estimated with M-Plus. The vector α of parameters of the measurement equations and the vectors β's of parameters of the structural equations were estimated simultaneously by using Maximum Likelihood with Huber-White covariance adjustment (Yuan & Bentler, 2000) and standard errors from the White's sandwich-based estimator that produces robust statistics in the presence of non-normality of the indicators and the categorical variables (White, 1980), and goodness-of-fit (Browne & Cudeck, 1993) was evaluated with the traditional descriptive measure of chi-square test alongside the Root Mean Square of Approximation (RMSA) and the Standardized Root Mean Square Residual (SRMR).

5. Results

5.1 Sample characteristics

The survey yielded 1,867 questionnaires, of which 1,512 (81%) were completed without missing data and thus served for data analysis and model estimation. The sample size is much larger than Nunnally's (50) widely applied rule of thumb for the

lower bound of sample size adequacy for SEM analysis that requires 10 observations for each of the 33 indicators used in the survey.

The sample demographics suggest reasonable heterogeneity and distribution across the variable categories. Among the respondents, 48.7% are male, 19.6% are adolescents and young adults (15-20 year olds), 25.6% are in their early twenties, 21.6% are in their late twenties, 8.5% are in their early thirties, and 24.7% are in their late thirties and forties. In terms of family status, 38.9% are single without children, 36.8% are in a relationship without children, 20.3% are in a relationship with children, and the remaining 4.0% are single with children. Most of the respondents have academic education: 51.8% have a university degree, 15.0% have college education, 32.1% attended vocational or upper secondary school, and only 1.1% have elementary school education. The monthly income of the respondents is 1,500 USD or less for 47.8%, between 1,500 and 4,300 USD for 20.0%, higher than 4,300 USD for 22.4%, and not disclosed for 9.5%. The regional distribution of the respondents covers all the five regions of Denmark, as 48.5% live in the Copenhagen Capital Region, 4.6% live in Sealand, 22.4% live in Southern Denmark, 21.2% reside in North Jutland and 3.3% reside in Middle Jutland.

The cycling habits of the respondents show that they are dedicated cyclists: 90.0% of the respondents have been cycling five years or more, 67.2% cycle daily, 15.5% cycle at least twice a week, 5.3% cycle once a week, and only 12.0 cycle in a lesser frequency. The distance cycled per day is 10 km or less for 57.1%, 11-20 km for 30.8%, 21-30 km for 8.1%, and more than 30 km for the remaining 4.0%. Most of the respondents use the bicycle for utilitarian purposes, as 49.0% views it only as a commuting mode and 47.4% views it as both a commuting mode and a sport activity, while only 3.6% use the bicycle exclusively for recreation.

The majority of the respondents (61.6%) indicated that they were involved in a cycling accident during the last 10 years. For the purpose of this study, a cycling accident was defined as either falling off the bike on the road or a bike path, running into another cyclist or pedestrian, or having a collision with a motorized vehicle. Among the respondents, 33.0% recalled their involvement in a single incident, 31.0% in two incidents, 16.6% in three incidents, and 19.5% in four or more incidents. When requested to provide information regarding the most recent cycling incident, in order to reduce the recall bias and the burden of an otherwise longer survey, the last incident occurred in the last year for 33.5% of the respondents, 1-2 years before the survey for 26.9%, 3-5 years before the survey for 24.0%, and more than 5 years before the survey for 15.6%. Among the most recent incidents, 54.7% had only the cyclist involved, 24.3% had another cyclist or a pedestrian involved, and 24.0% had also a motor vehicle involved. The location of the accident was close to the residence, less than 10 min cycling from home for 58.4%, and between 11 and 20 min cycling for another 27.1%. The reported injuries were limb bruising or abrasions in 66.1% of the cases, intense limb pain and swelling in 18.1%, back and neck pain in 5.9%, and memory loss, missed balance, and nausea were reported in 9.9% of the cases. Notably, only 38.4% of the

respondents reported their incidents and, conditional on the reporting group, 14.7% reported to the police, 41.8% to the hospital, 30.5% to their personal doctor, 7.8% to the emergency hotline, and 5.3% went to the pharmacy.

5.2 Accident reporting intentions

When asked whether they knew that the data gathered from accident reporting is used for research purposes, 21.8% of the respondents answered positively, 12.8% indicated that they were unsure but they suspected it, 62.1% replied that they did not know but it was interesting to know, and 3.3% stated that they did not know and found not interest in this piece of information. When asked whether they would report an incident in the future, provided that the information is used to improve traffic safety, 57.8% of the respondents replied positively and specified that they would do it to the hospital (18.2%), the police (31.9%) or both authorities (49.9%). When asked whether incentives would encourage them to report an incident, 49.3% of the respondents said that they would do it in the same way as now, but these percentages reached 84.1% if accident reporting was mandatory, 93.8% if data would serve research purposes, 72.8% if a mobile app was available, 81.2% if an internet reporting website was available, and 66.1% if each report would contribute 10 DKK for cycling infrastructure.

Initially, exploratory factor analysis elicited attitudes, subjective norms and perceived behavioural control related to accident reporting. The indicators in the survey show good internal consistency (Cronbach's Alpha = 0.847) and good sampling adequacy at the overall level (Kaiser-Meyer-Olkin = 0.864) and the single item level (Kaiser-Meyer-Olkin = 0.768 - 0.924). Most relevantly, exploratory principal axis factor analysis with Varimax orthogonal rotation uncovered the expected five factors: "attitudes that accident reporting is useless", "preference to allocate time to other activities", "concerns about family distress and social image", "distrust in the police", and "medical consultation aversion". These five factors were considered with their respective indicators in the SEM measurement equations.

Goodness-of-fit indices revealed that the proposed TPB approach incorporating cognitive dissonance, where the attitudes relate to the perceived behavioural control, is by far better suited to the data when compared to the traditional TPB approach. For the traditional TPB approach, the CFI is 0.691, the ratio between chi-square and degrees of freedom is 5.68, the RMSEA is equal to 0.056, and the SRMR is 0.078. For the proposed TPB approach, the CFI is 0.852, the ratio between chi-square and degrees of freedom is 3.50, the RMSEA is equal to 0.041, and the SRMR is 0.054. Accordingly, the model estimates and their critical ratios (C.R.) are presented only for the proposed TPB approach incorporating cognitive dissonance: measurement equations are presented in Table 1, structural equations linking the TPB constructs to cyclists' characteristics are shown in Table 2, structural equations linking the reporting intentions to the TPB constructs are illustrated in Table 3.

Table 1. Estimates of the measurement equations

Indicator	Estimate	C.R.
Attitudes that cycling accident reporting is useless		
I think that the police can help with determining the party at fault (R)	1.000	-
I think it is my civil duty to report (R)	1.491	13.53
I do not think the police usually write report on bicycle accidents	0.976	9.66
I think it will take a long time for the emergency forces to arrive to the scence	1.455	12.32
I think, that the police will not be able to help, because the damage is already done	1.854	13.48
I do not want to disturb the police or the hospital	1.283	10.92
I will not report if I do not think that I am injured	1.721	12.89
Police and the hospital authorities think it is unnecessary to report a bicycle accident	1.442	11.62
Generally, people tend not to report a bicycle accident	2.024	14.12
Preference to allocate time to other activities		
I think my work is more important than reporting a bicycle accident	1.000	-
I think my time could be better spent on other things than to report a bicycle accident	1.053	64.40
I do not think it is necessary to report a bicycle accident	0.802	42.30
Concerns about family distress and social image		
People I know who have had a bicycle accident, reported it (R)	1.000	-
My family thinks it is a waste of time to report a bicycle accident	1.752	17.92
My friends and colleagues think it is a waste of time to report a bicycle accident	1.674	17.66
My friends will think I'm clumsy, if they knew I had a bicycle accident	0.707	10.56
Distrust in the police		
I will not report because I do not trust the police	1.000	-
I think that the police think they are better than everyone else	1.278	34.13
I do not think that police officers are friendly	1.264	34.04
I think that the police are always happy to help (R)	1.251	34.06
I think that the police are good at doing their job (R)	1.307	34.73
I do not think that the police are effective	1.146	32.33
I do not think that the police help when you finally need them	1.138	31.74
Medical consultation aversion		
I do not want to be checked by a doctor	1.000	-
I always think that doctors are there to help (R)	0.970	12.38
I have had some bad experiences with doctors	1.199	12.29
I go to the doctor when I need advice. Better once too often than once too little (R)	1.359	12.91
I go to the doctor if I think I need prescription for medication or a vaccine (R)	1.587	13.37
I go to the doctor if I feel very sick (e.g. troubles to get out of bed, severe pain) (R)	1.379	13.13
I never go to the doctor	1.409	12.68
I am generally good at evaluating my own health (R)	0.847	9.91
I am generally do not have time to think about my own health	1.277	12.60
I prefer not to undergo health checks, so they would not find anything	1.335	12.25
I generally use my energy to be in good health (R)	0.733	8.74

When examining the estimates of the structural equations in Table 2, the TPB constructs are mainly related to the respondents' demographics and the last accident characteristics rather than to the respondents' cycling habits.

Attitudes that bicycle accident reporting is useless are stronger for respondents who are females, have children, reside in the Copenhagen Capital Region, are both recreational and utilitarian cyclists, and have high income. Moreover, respondents who were involved in an accident with another cyclist or pedestrian and presented concussion symptoms have stronger attitudes that reporting is useless, while respondents who reported their last cycling accident to the authorities (i.e., police, hospital, own doctor) have weaker attitudes.

The preference to allocate time to other activities instead of reporting the bicycle accident are stronger for male and highly-educated respondents, as well as for cyclists who suffered only limb bruises in their last cycling accident. Moreover, the preference to allocate time to other activities is weaker for people who have children, reside in the Central region of Denmark and estimated their daily cycling to be less than 20 km.

The concerns regarding family distress and social image are stronger for males and, to a lesser degree of statistical significance, respondents cycling less than 10 km daily. The concerns are stronger for respondents who experienced only limb bruises in their last accident, and are weaker for respondents who were involved in an accident with a motorist and chose to report their last accident to the authorities (i.e., police, hospital, own doctor).

The distrust in the police is stronger for respondents who are males, have low or medium income, and reside in the Copenhagen Capital Region. The distrust is lower for respondents who cover larger distances daily (20-30 km), but it is higher for respondents who suffered symptoms of concussion, or cannot remember their symptoms in the last cycling accident.

The medical consultation aversion is stronger for respondents who are males, reside in rural areas, have low income and do not have children. The medical consultation aversion is negatively related to longer cycling experience and it is weaker for respondents who reported their last cycling accident to their personal doctor or (to a lesser statistical significance) to the emergency hotline. Lastly, the medical consultation aversion is stronger for respondents who suffered from concussion in the last cycling accident or cannot remember their symptoms as well as they cannot remember whether they were alone in that situation.

When examining the estimates of the structural equations in Table 3, the reporting intentions of the next cycling accident are directly and negatively related to the attitudes that cycling accident reporting is useless (attitudes), the concerns about family distress and social image (social norms) and the medical consultation aversion (perceived behavioural control).

Table 2. Estimates of the structural equations explaining the TPB constructs

Attitudes that cycling accident reporting is useless		
Variable	**Est.**	**C.R.**
Demographics:		
Male	-0.082	-4.30
Has children	0.098	4.11
Region of Southern Denmark	-0.050	-1.83
Central Denmark Region	-0.073	-1.53
North Denmark Region	-0.068	-2.33
Monthly income: 10-30K	0.052	2.24
Monthly income - unknown	-0.122	-3.33
Cycling habits:		
Experience: 3-5 years	0.086	1.45
The last cycling accident:		
3-5 years ago	0.125	1.61
VRU involved as other party	0.079	2.52
Symptoms of concussion	0.099	2.33
Severe pain in hand/arm	0.053	1.53
Reported to police	-0.173	-3.81
Reported to hospital	-0.122	-3.75
Reported to 1813	0.109	1.49
Reported to pharmacy	-0.228	-2.83

Preference to allocate time to other activities		
Variable	**Est.**	**C.R.**
Demographics:		
Male	0.125	2.54
Has children	-0.247	-3.88
Central Denmark Region	-0.311	-2.06
High Education	0.233	2.25
Monthly income: 10-30K	-0.129	-1.78
Cycling habits:		
Daily distance :< 11 km	-0.252	-2.17
Daily distance: 11-20 km	-0.350	-2.96
Daily distance: 21-30 km	-0.275	-1.89
The last cycling accident:		
Bruises on the legs	0.130	2.17

Concerns about family distress and social image		
Variable	**Est.**	**C.R.**
Demographics:		
Male	0.089	2.92
21-24 years old	-0.060	-1.54
Monthly income: Unknown	0.080	1.35
Cycling habits:		
Daily distance: < 11 km	0.129	1.70
Daily distance: 11-20 km	0.098	1.29
The last cycling accident:		
Accident < 1 year ago	0.354	5.65
Accident 1-2 years ago	0.305	4.76
Accident > 5 years ago	0.362	4.80
Car involved as other party	-0.130	-2.60
Bruises on the legs	0.112	2.87
Reported to police	-0.263	-3.13
Reported to hospital	-0.123	-2.14
Reported to personal doctor	-0.140	-2.14

Distrust in the police		
Variable	**Est.**	**C.R.**
Demographics:		
Male	0.094	2.57
21-24 years old	-0.074	-1.61
Has children	-0.090	-1.90
Region of Southern DK	-0.121	-2.47
Central Denmark Region	-0.181	-1.74
North Denmark Region	-0.171	-3.31
Monthly income < 10K	0.180	3.34
Monthly income 10-30K	0.111	2.05
Monthly income: Unknown	0.311	4.28
Cycling habits:		
Daily distance 21-30 km	-0.239	-2.24
The last cycling accident:		
Company: Can't remember	0.385	1.66
Symptoms of concussion	0.227	2.60
Pains in arm/hand	0.102	1.57

Can't remember symptoms	0.281	1.93
Reported to pharmacy	-0.245	-1.50

Medical Consultation aversion		
Variable	**Est.**	**C.R.**
Demographics:		
Male	0.112	4.33
Has children	-0.089	-2.58
Residence in rural areas	0.139	2.84
Monthly income: < 10K	0.073	1.91
Monthly income: Unknown	0.220	4.04
Cycling habits:		
Experience:> 5 years	-0.098	-1.86
The last cycling accident:		
Accident 3-5 years ago	-0.245	-2.03
Accident > 5 years ago	-0.188	-1.56
Accompany: Child	0.225	1.55
Accompany: Teen	0.212	1.96
Accompany: Adult	0.170	1.50
Accompany: Not remember	0.279	2.04
Symptoms of concussion	0.148	2.48
Cannot remember symptoms	0.169	1.84
Reported to personal doctor	-0.099	-1.96
Reported to 1813	-0.129	-1.30

The results confirm the research hypotheses that the attitudes are directly related to the perceived behavioural control. The most relevant factors for reporting are the attitudes that cycling accident reporting is useless and the concerns regarding family distress and social image. The most important factor related to the attitudes that cycling accident reporting is useless is the preference to allocate time to other activities, while the most important related to the preference to allocate time to other activities is the concern about the family distress and social image.

Table 3. Estimates of the structural equations explaining cycling accident reporting intentions

Variable	**Estimate**	**C.R.**
Accident reporting intentions		
Attitudes that cycling accident reporting is useless	-0.964	-6.41
Medical consultation aversion	-0.217	-2.36
Concerns about family distress and social image	-0.551	-5.25
Attitudes that cycling accident reporting is useless		
Distrust in the police	0.066	5.35
Medical consultation aversion	0.238	7.42

Preference to allocate time to other activities	0.326	13.76
Preference to allocate time to other activities		
Distrust in the police	0.166	4.74
Concerns about family distress and social image	1.215	16.97

6. Conclusions

This study proposes a novel behavioural framework for exploring the behavioural factors motivating the intentions to report cycling accidents, based on a non-traditional formulation of the TPB approach. The results stimulate thoughts about policy implications for increasing accident reporting in general, and cycling accident reporting in particular.

Firstly, the findings confirm the hypothesis that not only the reporting intentions, but also the attitudes towards cycling accident reporting, are directly related to the perceived difficulties to report. Applying the traditional TPB framework, where attitudes and perceived behavioural control are only related in the error terms because they pertain to the same individual, would imply that policy measures can be applied for changing people's attitudes towards reporting without resolving the perceived difficulties. Applying the novel TPB approach, which incorporates the cognitive dissonance theory and relates the attitudes to the perceived difficulties, implies that the difficulties associated with accident reporting need to be resolved in combination or prior to awareness campaigns about accident reporting. This result has an implication also on incident reporting in general, as assuming the traditional TPB approach without testing for the existence of cognitive dissonance could generate suboptimal and biased solutions, leading to ineffective policy solutions.

Secondly, attitudes that accident reporting is useless are the most relevant factor related to the lack of intention to report future accidents. The perceived uselessness of accident reporting is in contradiction to its factual usefulness for improving traffic safety. The reason is that the perceived uselessness of reporting is directly related to the subjective norms and perceived difficulties to report, rather than the factual knowledge regarding the societal benefits of reporting. In fact, respondents exhibited in the survey a general lack of knowledge regarding the societal importance of accident reporting and the use of accident reports for research aiming at improving traffic safety. Most respondents stated though that they were pleased to learn about the societal benefits of accident reporting and indicated a willingness to report future accidents provided that their report would be used to improve traffic safety. Respondents also suggested that relating the reporting system to direct monetary incentives for improving cycling safety is also appealing. Therefore, campaigns should address the societal usefulness of accident reporting with the aim of increasing road incident reporting, and more specifically awareness campaigns could serve as a tool to increase the knowledge regarding the factual usefulness of accident reporting and to generate positive social norms in favour of accident reporting.

Thirdly, concerns about family distress and social image are the second most important factor associated with both non-reporting intentions and the preference to allocate time to other activities. Policy measures should aim at generating a wider acceptance of the occurrence of accidents, reducing the embarrassment and guilt associated with such accidents, and emphasizing the importance of allocating time to accident reporting. For example, monetary incentives could be used to generate more favourable social norms towards cycling accident reporting. Needless to say, social norms should be addressed with respect to cycling accidents in particular, but also traffic accidents in general.

Lastly, the perceived difficulties to report to the authorities (mainly medical consultation aversion) and concerns regarding social distress are positively correlated with both non-reporting intentions and the preference to allocate time to other activities. Most of the cycling incidents occur close to the residence place, likely discouraging or postponing accident reporting, and two possible courses of action might resolve this situation. The first course of action is related to enhancing the speed and privacy of accident reporting as well as allowing the possibility to report without direct communication with the authorities. In fact, the respondents indicated that a mobile app or an internet website would facilitate the reporting process and hence would encourage them to report future cycling accidents. The reporting would be in real time, fast, without the need for direct contact with the authorities or to inform the close social circle, and hence this technological solutions would mitigate the perceived difficulties involving communication with the authorities and the distress associated worth social image. The second course of action is related to enhancing the service quality management of the reporting bureaucracy, given that under-reporting of cycling accidents is associated with the attitudes and difficulties related to the accident reporting beurocracy. Further research will aim at understanding the external stimuli underlying cyclists' perceptions of the reporting system as a whole, and in particular the relationship between cyclists' perceptions of reporting difficulty and quality service management of the accident reporting bureaucracy. Findings would then enable the police and the medical system to improve the customer service and experience with respect to accident reporting, especially n the case of light injuries or material damage.

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PAPER 4

Evaluating the police service quality for handling traffic crash reporting: a combined MCDA and LCA approach

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Abstract

This study investigates the police service quality for handling the reporting of traffic crashes. We have developed an approach that combines Multi-Criteria Decision Analysis with Latent Class Analysis and we have designed a web-based questionnaire for its implementation. This built upon the SERVQUAL approach to detecting strengths, opportunities and threats with crash reporting to the police at a strategic level. The survey was administered to stakeholders in the field of transportation with some interest in traffic safety in Denmark. The survey yielded 86 questionnaires, which were analysed by a Multi-Criteria Decision Analysis technique and clustered with Latent Class Analysis. The newly developed approach was successfully applied and its implementation demonstrated the usefulness of the tool even in countries with a high police service. Results showed that the participating stakeholders perceived human factors as more important than physical factors in order to increase the reporting rate of traffic crashes, with responsiveness as the most important and tangibles as the least important dimensions. Nevertheless, most experts viewed a mixture of human and physical factors as important to increase the reporting rate.

Keywords: Traffic crash reporting, police distrust, SERVQUAL, latent class analysis, multi-criteria decision analysis.

1. Introduction

Due to the increasing reliance on traffic crash data for identifying infrastructure, human and mechanical risk factors underlying crash occurrence and severity, concerns regarding the responsiveness of traffic crash data have gained a lot of attention, questioning the trustworthiness of the variables in the analysed datasets and the extent of the under-reporting phenomenon (e.g., Elvik & Mysen, 1999; Yannis et al., 2014; Abay, 2015). Studies comparing police and emergency room crash databases (Elvik & Mysen, 1999; Yannis et al., 2014; Watson et al., 2015) have found high under-reporting rates in many countries, and the reporting rate varies considerably with road user type and crash severity (Elvik & Mysen, 1999; Farmer, 2003; Amoros et al., 2007; McDonald et al., 2009), and it is subject to selection bias (Janstrup et al. forthcoming).

The perceived reporting usefulness and police distrust play a role in under-reporting (Amoros et al., 2007; Kaplan et al., 2016). Police distrust is important in the case of traffic crash reporting due to a dual role of the police as a service provider and authority. Distrust in the police, interpreted as a psychological state with negative feelings towards the police as an institution, was mentioned as a severe impeding factor to incident reporting in studies involving domestic violence and sexual assault (Jones et al., 2009). Police distrust in countries with high societal trust, such as Scandinavian societies, has been found to be associated with low crime reporting rate (Kääriäinen & Siren, 2011). Last, police distrust has been found to be directly related to perceived crash reporting usefulness, which is directly connected to traffic crash reporting intentions among cyclists in Denmark (Kaplan et al., 2016).

During the last decade, police agencies have become increasingly aware that achieving public safety and security goals largely depend on establishing trust in the community via their role as public service providers in addition to their role as traditional law enforcement. Therefore, police agencies have become more consumer-oriented, increasing their service quality in terms of accessibility and staff commitment (Drummond et al., 2000; Cukier et al., 2012), as service quality is considered essential for establishing trust in both the private and the public sector (Brysland & Curry, 2001; Kumar et al., 2009; Catulli, 2012; Li et al., 2015).

The focus on service quality has led police agencies to use the SERVQUAL tool developed by Parasuraman, Zeithaml and Berry (1985) to identify the main components of police service quality (Mastrofski, 1999; Donnelly et al., 2006; Maguire & Johnson, 2010; Akhtar et al., 2011). The main focus so far has been on either the perceived police service quality by the general public (Maguire & Johnson, 2010) and the difference between expected and perceived service quality (Donnelly et al., 2006).

The current study extends the body of knowledge by focusing on the police service quality in handling traffic crash reporting. The importance of this issue stems from the need to increase the extent and the quality of traffic crash reporting, and from the large share of traffic accident reporting in people' incident reporting to the police (Maguire & Johnson, 2010). In particular, we offer a new expert-based decision support tool that

enables stakeholders to evaluate the overall service quality in traffic crash reporting, detect opportunities and barriers for increasing the crash reporting rate, and prioritize service quality issues. The proposed approach comprises a combination of the SERVQUAL model adapted to the context of handling traffic crash reporting as its core, an expert-based multi-criteria decision analysis (MCDA), and latent class clustering (LCA) to handle stakeholders' heterogeneity. The MCDA approach has previously been used to assist in the evaluation of transport projects, policies and investments (Tudela et al., 2006; Barfod, 2012; Wang et al., 2014; Macharis & Bernardini, 2015), but it is rarely used for service quality assessment. A recent example is the use of MCDA as an evaluation tool for service quality in the healthcare system (Oddershede et al., 2014). This study is to the authors' knowledge the first to apply MCDA for police service quality assessment. In traditional MCDA techniques, heterogeneity across stakeholders is captured through majority versus minority opinion or through stakeholders' socio-economic characteristics. This study is the first to consider LCA as a multi-dimensional tool for clustering stakeholders that enables to consider simultaneously opinion and socio-economic differences. The results of this study provide new insights on the perceived police service quality for handling crash reporting and highlight where improvement should be made in order to benefit the reporting rate the most. The method is applied in Denmark, demonstrating the usefulness of the tool even in countries with generally high police service quality.

The remainder of the paper is organized as follows. The next section presents the three elements of the proposed approach (i.e. SERVQUAL, MCDA and LCA). Section three presents the application of the proposed tool to the Danish case study. Section four presents the results according to different clusters for strengths, opportunities and threats for the police when handling crash reporting. Last, major findings are discussed and concluding remarks are presented.

2. Methodology

Figure 1 presents the proposed integrated service quality evaluation framework that integrates the SERVQUAL tool, the expert-based MCDA technique, and the LCA approach, with the aim of evaluating the police service quality in handling the reporting of traffic crashes. The method is easily transferrable to service quality assessment in other fields, for example evaluating the quality of service in public transport. The following sections detail each element.

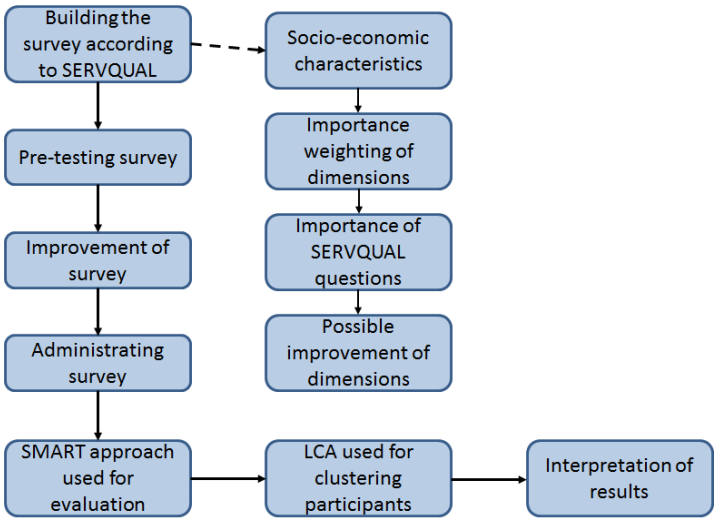

Figure 1: Study and questionnaire structure

2.1 The SERVQUAL Tool

The core of the framework is driven by Mastrofski's Six Domains of Performance (Mastrofski, 1999), a tool used to measure police performance. Mastrofski's domains are inspired by the SERVQUAL framework (Parasuraman et al., 1985) which is applied to measure service quality in the private sector and is built upon ten possible dimensions (i.e., reliability, responsiveness, competence, access, courtesy, communication, credibility, security, understanding, tangibles). Mastrofski (1999) found the following six dimensions as relevant to police agencies in service provision to the general public: attentiveness, reliability, responsiveness, competence, caring, and fairness. Previous studies have used Mastrofski's dimensions to evaluate the perceived police service quality in several countries including Pakistan (Akhtar et al., 2011), Taiwan (Chu et al., 2010), U.S. (Maguire & Johnson, 2010) and U.K. (Donnelly et al., 2006).

Previous studies have two major limitations, as noted by Maguire and Johnson (2010) and Donnelly et al. (2006), which are resolved in the proposed framework. The first limitation is that they evaluated the perceived service quality for handling a wide range of incidents while disregarding the differences across incidents in terms of severity, occurrence probability, target population, required communication skills, and expertise. In this study, we focused on the service quality needs for traffic crash reporting while considering the unique nature of traffic crashes that are unintentional violent incidents resulting in a range of consequences from damage only to fatal injuries, are relatively common among the general population, and in which the party at fault is often difficult to determine. The second limitation is that they focused on the perceptions of the general public as the customer perspective or on the police viewpoint, which while carrying important benefits, has also some limitations such as the possibility of biases due to strategic response bias, emotional bias, and layman

opinion. In this study, we resolved this issue by taking an external expert-based perspective.

Given the premises, this study postulates that the following dimensions have an impact on service quality within the police when handling reporting of traffic crashes.

Accessibility: the attitudes regarding the usefulness of crash reporting are related to delays in the police arrival time to the crash scene, ability of the police to help provided that the damage is done, and concerns of road users regarding disturbing the police (Kaplan et al., 2016). Increasing the accessibility of the police to the general public, defined as the perception of the police as available and accessible (Maguire & Johnson, 2010), may be related to increasing the perceived usefulness of crash reporting. In this study we define accessibility as perceived ease of contacting the police when reporting a traffic crash, prompt response by phone, short travel time to the police station, and short arrival time of the police to the crash scene.

Tangibles: the interior and exterior design of police stations are associated with public perceptions of the police authority, approachability, and professionalism (Clinton & Devlin, 2011) and thus may be associated with increased feeling of trust and accessibility, which in turn can result in higher reporting rates. In this study, the tangibles, defined as the appearance and functionality of the physical facilities, equipment and communication materials (Donnelly et al., 2006), comprise nice and clean waiting environments, quiet and relaxing surroundings, and availability of computer-based documentation.

Responsiveness: time-constraints and perceptions of the reporting system as non-flexible, cumbersome, complex, and time-consuming to complete, are major barriers to incident reporting (Kongsvik et al., 2012; Lindsay et al., 2012; Williams et al., 2013; Winswold Prang & Jelsness-Jørgensen, 2014). Similarly, attitudes regarding the usefulness of traffic crash reporting and its associated time-efficiency are major barriers to traffic crash reporting (Kaplan et al., 2016). Police responsiveness, defined as the willingness to help customers and provide prompt service (Donnelly et al., 2006), can potentially mitigate these concerns and increase the traffic crash reporting rate. In this study, we define police responsiveness as encompassing short waiting times, quick reporting procedures, good information provision to facilitate the reporting procedures, handling crash reporting effectively, and allocating sufficient time slots for reporting.

Caring: as it is commonly recognized that human errors play a major role in traffic crashes, recent studies showed that traffic crash victims experience self-blame and guilt (Peltzer & Renner, 2004) and concerns regarding family distress and social image are barriers for the intentions to report traffic crashes (Kaplan et al., 2016).

Caring, defined as the individualised attention an organisation provides to its customers (Donnelly et al., 2006), may be an important service quality aspect that can potentially mitigate these concerns and increase the trust in the police. In fact, Kaplan,

Janstrup and Prato (2016) found that trust in the police is also related to the friendliness and readiness to help of the police officers. In this study, we define caring as general friendliness and positive attitude, respect, and supportive non-violent communication focusing on understanding the needs of people who arrive to report traffic crashes.

Fairness: police distrust is directly related to attitudes regarding crash reporting usefulness and preferences to allocate time to other activities instead of the civic duty of crash reporting, which are directly related to lower crash reporting intentions (Kaplan et al., 2016). Increasing the trust in the police may change these trends towards higher perceived reporting usefulness and reporting intentions. Fairness is an important quality of service dimension which is related to trust (Maguire & Johnson, 2006). In this study, we refer to procedural and interactional fairness, namely fairness with respect to the process leading to an outcome and the interpersonal interaction between the decision maker and the individuals affected by the decision (Maguire & Johnson, 2006). Specifically, we associate interactional fairness with a neutral and fair treatment of the reporting party, and procedural fairness with allocating sufficient time to record the incident, allocating specialized and skilled personnel to handle the reporting procedure, and precise and correct registration of the report.

2.2 Multi-Criteria Decision Analysis Technique

The SERVQUAL scale serves as the basis for an expert-based MCDA evaluation process. MCDA is a sub-discipline of operations research which explicitly considers multiple criteria in decision-making often used among an expert panel. The method is based on the decomposition approach, namely the divide-and-conquer (DAC) principle (dividing the large and often complex problem into smaller units that can be dealt with more easily). In this study, the method is used to identify service strengths, opportunities, threats and possible policies subjects to improve the reporting of traffic crashes. The method is a combination of the SERVQUAL scale and the SMART (Simple Multi-Attribute Rating Technique) approach by Von Winterfeldt and Edwards (1986). SMART is an MCDA method that allows evaluating a finite number of decision alternatives with respect to a finite number of performance criteria. SMART is based on the additive value function model and assigns direct scores to alternatives and direct weights to criteria using a scale defined for the specific problem in hand (Barfod & Salling 2015).

Input for the method is derived by using a panel of experts (i.e., stakeholders, decision-makers), which can be elicited by applying standard procedures (see, e.g., Sackman, 1974; Edwards & Barron, 1994), as conducted for example in the works of Shiftan, Kaplan and Hakkert (2003) and Wang et al. (2014). In this study, the Delphi-method (Sackman, 1974) is used which gives no limitations for the number of experts (or stakeholders). Early Delphi studies were mostly conducted to concern scientific and technological forecasting and thought of as experiments. The questionnaire technique has later been used in social science and also developed for non-expert panels, but in these cases a pilot testing is needed to get a minimal professional standard. For this study, stakeholders in the transport field (e.g. researchers, authorities, consultants,

NGO representatives) and transport suppliers are used for both pilot testing and final survey.

After selecting the firms and universities for administering the survey, the following four consecutive steps were conducted.

The first step consisted of using the SERVQUAL scale in order to detect strengths, opportunities and threats dimensions associated with handling reporting of traffic crashes (e.g. accessibility, tangibles, responsiveness, caring and fairness). The second and the third steps concerned the rating of the strengths, opportunities and threats in each dimension in terms of their relative importance. In these two steps, taking a decomposition approach, each of the detected strengths, opportunities and threats were evaluated as separate items by applying the SMART procedure.

For the second step, namely evaluating the impact (score) of the challenges and opportunities for each dimension, the SMART technique was applied. The purpose of the analysis is to rank the dimensions in a subjective order of preference and rate the overall impact. In the technique, ratings (scores) are assigned directly in the natural scales of the attributes.

In the third step, the SMART technique was applied for eliciting criteria weights. By using a visually supported scale, the respondents considered the importance of each item on a 5 point Likert-scale. Traditionally much larger scales are used in this step, but in order to fit the method to a large-scale questionnaire some adjustment (simplification) was necessary.

SMART is based on a linear additive model which implies that the overall value of a specific item following is calculated as the total sum of the performance score multiplied with the weights.

The last step was a reflecting procedure where the respondents were requested to state the improvement possibilities for the reporting of crashes if the problems in some of the dimensions are solved. These questions give the respondents a possibility of reflecting about their previously answers in the most important part of the questionnaire.

2.3 Model-Based Clustering

An expert-based evaluation process may result in either a consensus or several different opinions, and a single solution is not mandatory (Shiftan et al., 2003). Besides majority opinion, having a range of solutions is important as a sensitivity analysis in order to increase the robustness of the MCDA approach by mapping sources of uncertainty (e.g., Barfod & Salling, 2012). In this study, a multi-dimensional model-based technique is used to differentiate among the stakeholders according to their opinions, social and professional characteristics in order to identify a possible range of alternative solutions.

An LCA technique is used instead of traditional clustering approaches where the clusters are made according to the stakeholders' socio-economic or professional characteristics. Since the number of clusters and their form are unknown, the method can be considered as an unsupervised learning approach (e.g., Magidson & Vermunt, 2002; Depaire et al., 2008). While LCA was conceived more than four decades ago, only recently renewed interest in its application and advances in computational capabilities led to wide-spread applications in a diversity of social science studies (see, e.g., Vermunt & Magidson, 2002; Lanza et al., 2007).

The main advantages of LCA over alternative and traditional clustering approach (e.g., k-means clustering, hierarchical clustering) are the ability to represent overlap across clusters rather than only independent or nested clusters, the existence of an underlying statistical model that allows calculating cluster probabilities for new cases, and the provision of several goodness-of-fit criteria that facilitate the decision regarding the number of clusters (Kaplan & Prato, 2013; Weiss et al., 2015). LCA technique was performed in the current study by using the SAS procedure developed by Lanza et al. (2007).

LCA is defined as the classification of similar objects into C latent classes, where their size is unknown and uncertainty is involved in the class membership and the number of clusters. Now assume that N observations forms a vector which are characterized by another vector of M variables ($y_i = y_1,\ldots,y_M$), and let ($Y_i=Y_{i1},\ldots,Y_{iM}$) be the vector of values of observation i for the M items. Then, the latent class model is as follows (see, Depaire et al., 2008; Kaplan & Prato, 2013):

$$p\left(Y_i \mid \theta\right) = \sum_{k=1}^{K} P\left(C_k\right) p\left(Y_i \mid C_k, \theta_k\right) \tag{1}$$

where ($k=1,\ldots,K$) indicate a latent class, K is the number of latent classes, $P(C_k)$ denotes the prevalence of latent class C_k in the dataset, θ_k is a vector of unknown parameters to be estimated, and $p(Y_i \mid C_k,\theta_k)$ denotes the conditional multivariate probability that an observation in class C_k would be characterized by Y_i.

Simplifying assumptions should be made in order to derive an estimable model formulation with reasonable parametric complexity. In this study, the following assumptions are made prior to model estimation. Firstly, every variable i in the model is assumed to be an ordinal indicator with R_m possible responses ($r_{mi} =1,\ldots,R_{mi}$). Secondly, the observations are assumed to be uncorrelated, which is a reasonable assumption. Thirdly, the categorical indicators are assumed to be independent within a latent class, namely the within-class covariance matrix is assumed to be diagonal (local independence), which is important to maintain a parsimonious model structure. Last, all the categorical indicators are assumed to be endogenous indicators of the latent class, and thus no covariates are employed to predict class membership. Under these conditions, the LCA model can be formulated by the following (Lanza et al., 2007):

$$p(Y_i \mid \theta) = \sum_{k=1}^{K} \pi_k \prod_{m=1}^{M} \prod_{r_m=1}^{R_m} \theta_{mr_m|k}^{I(y_{im}=r_m)} \quad (2)$$

where k is the latent class that observation i is member of, I is an indicator function that equals 1 if y_{im} equals r_m and 0 otherwise, π_k and θ_{mrm} are parameters to be estimated. The parameters π_k represent class membership probabilities and θ_{mrm} are indicator response probabilities conditional on the latent class membership.

The LCA parameters are estimated by maximum likelihood using the expectation-maximization (EM) algorithm (Lanza et al., 2007). Convergence is achieved when the maximum absolute deviation (MAD) is less than 1E-06. Notably, the likelihood function in LCA is not necessarily concave and therefore a well-known problem is that the EM algorithm converges to local maxima rather than to a global maximum. A commonly used procedure for decreasing the likelihood of reaching a local maxima consists in using multiple sets of starting values (for details, see Vermunt & Magidson, 2002), the LCA was performed with 50 sets of random starting values to increase the likelihood of convergence to the global maximum.

The Bayesian Information Criterion (BIC) determines the number of clusters due to its superiority on other goodness of fit measures in terms of consistency and accuracy (see e.g., Nylund et al., 2007). Following the recommendation of Lanza et al. (2007) and the example of traditional clustering approaches, the number of clusters was evaluated also on the basis of the ability to distinguish and interpret clusters of non-negligible size.

3. Data

3.1 Survey Design

The data were collected by a web-based questionnaire built upon the SERVQUAL scale developed in the current study to elicit stakeholders' perceptions regarding the police service quality for handling traffic crash reporting.

The questionnaire was divided into five parts. The first three parts elicited the stakeholders' characteristics. The first part elicited stakeholders' socio-economic characteristics (e.g., age, gender and workplace location) and professional experience with traffic safety and analysis with crash data. The second part elicited stakeholders' personal experience as a private person visiting the police for crash reporting or other reasons in the last five years. The third part elicited the stakeholders' perception regarding the importance of reporting of crashes to police and the rating of the five dimensions' importance for the handling of traffic crashes reporting.

The last two sections focused on eliciting the stakeholders viewpoint. In the fourth section, stakeholders stated their confidence level for answering questions about the police and rated the importance for each question within the five dimensions for reporting traffic crashes to the police. In the last section, the stakeholders answered

questions regarding their belief in the ability to improve crash reporting rates as a result of police service quality improvements. The questions were rated on a 5-point Likert scale.

3.2 Survey Administration

The questionnaire was administered among stakeholders in the transport field comprising of authorities, researchers, NGOs, consultants, transport providers. The preliminary version of the questionnaire was administered at the National Danish Transport Conference (Trafikdage) at Aalborg University. Due to the very low completion rate (39%) the survey was notably changed and shortened. The main difference between the original and the new version is the structure rather than the content. In particular, a 5-point Likert scale was used instead of an 11-point Likert scale, and reducing the number of questions by 50% by asking about improvements of the service quality instead of the current situation, the quality of service, and the ease of improving it. The new questionnaire was distributed to different consultancy companies (e.g., Cowi, Trafitec), transport suppliers (e.g., DSB, Banedanmark), authorities (e.g., The Danish Road Directorate, Municipalities, Police agencies), NGO's (e.g. Council for Safe Traffic, Danish Cyclist's Federation) and universities (e.g., DTU Transport, Aalborg University).

3.3 Sample Characteristics

The data in the pre-test ended up with 20 completed responses (39% completion rate), mainly of male stakeholders (75%) who are working for transport authorities (45%). The final questionnaire yielded 90 completed and valid responses out of 125 (72%). Incomplete responses from 4 respondents who rated all the questions with the same grade were removed before the analysis of the final data to maintain high data reliability. Among the stakeholders included in the analysis 59% were male and 41% were working for transport authorities, making it the largest interested stakeholders' group. Regarding age, 27% of the stakeholders were in the age group of 30-39 years old and another 28% were 50-59 years old. Regarding traffic safety, 94% of the stakeholders stated that they are interested and 30% declared to have visited a police station at least once in the last five years. Among the stakeholders, 29.1% had a high or very high confidence level and another 36.0% had a medium confidence level in their ability to evaluate the service quality for traffic crash reporting.

4. Results

4.1 Perceptions Regarding the Current Service Quality

A preliminary evaluation about the current service quality for handling traffic crash reporting and the perceived ease of improvement were retrieved from the preliminary version of the questionnaire which made use of an 11-point Likert scale (this question was removed from the final version because of length restrictions). The scale for service quality ranged between 0 (non existent) and 10 (excellent), while the scale for perceived ease of improving ranged from 0 (impossible) to 10 (already perfect).

Table 1. Survey questions and average value score with standard deviation in pre-test

Questions	Dimension	Current situation Average score	S.D.	Possibilities to improve Average score	S.D.
The travel time by car from home to the police station is short	Accessibility	4.80	2.04	4.70	2.70
Contacting the police is easy for reporting a traffic crash	Accessibility	6.45	2.64	5.90	2.79
The police answers the telephone in a timely manner	Accessibility	5.95	2.58	6.35	2.67
The police arrives to the crash scene in a timely manner	Accessibility	5.80	2.46	6.00	2.37
The police stations have nice and clean waiting areas	Tangibles	5.50	1.72	6.40	2.33
The police stations have quiet and relaxing indoor environments	Tangibles	5.35	2.15	5.55	2.16
The computer recording of traffic crashes at the police is easy	Tangibles	4.50	1.72	7.50	1.91
The police has electronic resources for correct registration of crash reports	Tangibles	4.80	2.09	7.20	1.44
The waiting time at police stations is short when reporting a traffic crash	Responsiveness	5.00	1.82	6.60	1.69
The police provides a prompt service when reporting a traffic crash	Responsiveness	5.30	1.85	6.45	1.66
The police provides good information to facilitate crash reporting	Responsiveness	5.50	2.29	6.55	1.88
The police resolve problems effectively related to crash reporting	Responsiveness	6.15	1.77	5.75	1.51
The allocates suffcient time for people who need to report a traffic crash	Responsiveness	5.50	2.27	6.05	2.25
The police officers are generally friendly and smiling	Caring	7.25	2.14	6.40	2.27
The police officers treat people who report traffic crashes with respect	Caring	7.15	2.52	6.15	2.31
The police officers help people feel safe	Caring	7.25	2.19	6.00	2.12
The police officers understand people's needs	Caring	6.20	2.46	6.20	1.78
There are police officers specialized in handling traffic crash reporting	Fairness	5.25	2.41	6.45	1.94
The police officers remain neutral and fair	Fairness	6.75	2.55	6.10	2.02
The police officers record traffic crashes correctly and precisely	Fairness	5.65	2.31	6.75	1.95
The police officers dedicate time for traffic crash reporting	Fairness	4.60	1.98	6.80	2.20

Note: The scale for service quality in current situation ranges between 0 (non existent) and 10 (excellent), while the scale for perceived ease of improving ranges from 0 (impossible) to 10 (already perfect).

The results of the preliminary questionnaire (see, table 1) indicated that the stakeholders perceived the service quality at police stations at a good level and that they were in general quite satisfied with the handling of traffic crash reporting within the police.

The differences in the perceived service quality across the five dimensions were relatively small, suggesting the lack of serious lacunas. The high score of the ***caring*** dimension was not surprising considering that the Danish society is a society with high social trust, but it suggested the opportunity for police agencies in other countries to explore the transferability of the Danish communication model in handling traffic crash reporting to other police agencies.

The stakeholders evaluated the dimension of ***tangibles*** as the dimension with the lowest service quality and the highest ease of improvement. The ***caring*** dimension was perceived as the dimension with the highest level of service and moderate ease of improvement.

The items that had a relatively low current service quality score (under 5.0) across all the dimensions were the travel time to police stations (***accessibility***), computer resources (***tangibles***), waiting time (***responsiveness***), and time allocated for crash reporting (***fairness***). Of these items, the computer resources were perceived as relatively easy to resolve while the travel time to the police station was perceived as the most difficult to improve.

4.2 Importance of Service Quality Dimensions for Improving the Reporting Rate

For the final questionnaire, the MCDA approach was used to achieve a better understanding of the responses and take the weighted importance of each dimension into consideration. Hence, the scores represent the importance for each question in the five dimensions when reporting a traffic crash to the police and are all weighted according to the overall importance of each dimension (e.g. ***accessibility***, ***tangibles***, ***responsiveness***, ***caring***, and ***fairness***).

Table 2 shows the weighted average score for each question in the five dimensions across the whole sample. The resulting scores are all normalized to sum to 1. The items in each dimension had similar scores, and thus the service quality evaluation can be dimension-based rather than item-based. The stakeholders view human factors of communication and interaction as more important to increase the crash reporting rate than physical factors, because ***responsiveness***, ***caring*** and ***fairness*** were perceived as more important than ***tangibles*** and ***accessibility***. The most important dimension is ***responsiveness***, while the least important is ***tangibles***.

Looking at the importance scores at the item level, the items with the lowest importance scores were travel time to the police stations and the ambiance in the police stations, while the items with the highest importance scores were allocating sufficient time resources for traffic crash reporting and resolving problems that arise in the process.

Table 2. Survey questions and the five dimensions

Items	Dimension	Mean importance score*
The travel time by car from home to the police station is short	Accessibility	0.0352
Contacting the police is easy for reporting a traffic crash	Accessibility	0.0462
The police answers the telephone in a timely manner	Accessibility	0.0472
The police arrives to the crash scene in a timely manner	Accessibility	0.0474
The police stations have nice and clean waiting areas	Tangibles	0.0334
The police stations have quiet and relaxing indoor environments	Tangibles	0.0353
The computer recording of traffic crashes at the police is easy	Tangibles	0.0468
The police has electronic resources for correct registration of crash reports	Tangibles	0.0443
The waiting time at police stations is short when reporting a traffic crash	Responsiveness	0.0525
The police provides a prompt service when reporting a traffic crash	Responsiveness	0.0555
The police provides good information to facilitate crash reporting	Responsiveness	0.0551
The police resolve problems effectively related to crash reporting	Responsiveness	0.0558
The police allocates suffcient time for people who need to report a traffic crash	Responsiveness	0.0558
The police officers are generally friendly and smiling	Caring	0.0462
The police officers treat people who report traffic crashes with respect	Caring	0.0515
The police officers help people feel safe	Caring	0.0469
The police officers understand people's needs	Caring	0.0493
There are police officers specialized in handling traffic crash reporting	Fairness	0.0435
The police officers remain neutral and fair	Fairness	0.0500
The police officers record traffic crashes correctly and precisely	Fairness	0.0527
The police officers dedicate time for traffic crash reporting	Fairness	0.0493

Note: * weighted mean importance score found with the SMART approach

4.3 Revealing a Range of Stakeholders Perspectives by Means of LCA

In this study the LCA approach was used to identify clusters for the 86 responses received from the stakeholder panel. The LCA was performed by using the categorical indicators corresponding to the respondent characteristics and their weighted opinion of importance for each dimension found by using the MCDA approach.

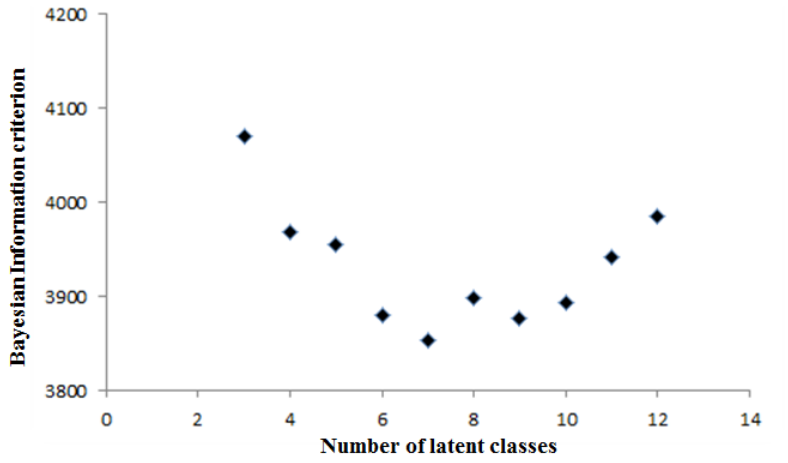

Figure 1: Graph of the BIC as a function of the number of latent classes

From the analysis, the LCA yielded 7 clusters according to the BIC criterion, as shown in Figure 2. The entropy criterion for this solution was 1.00, which indicates a very high certainty in the classification (Depaire, Wets and Vanhoof 2008). The seven clusters were sorted according to differences and similarities in their prevalent features (i.e. when over 55% of the observations had the same feature in the cluster).

Table 3 describes the stakeholders' characteristics, professional and personal experience, and perceptions regarding importance associated with each item in each cluster.

C1 is a cluster of professionals over 40, mainly researchers who work in Zealand and focus mainly on office work in the safety field. They have experience with reading, writing and analysing safety reports, do not have safety field or planning experience, perceive that contacting the police in the case of a crash is important, self-assess their certainty level in answering the questionnaire as low. Rank 3/4 items in ***accessibility*** and 2/4 items in ***tangibles*** as of medium/high importance, rank 5/5 items in ***responsiveness*** and 4/4 items in ***caring*** as of high importance, and rank 4/4 items in ***fairness*** as of low importance.

C2 is a cluster of male professionals, who work in public authorities or consultancy, mainly in Zealand and Southern Denmark. They have experience both with office and field work in traffic safety, because they have extensive experience with both reading and analzysing safety reports and traffic safety inspections, revisions and planning. Most of them have experience with analysing crash data and black-spots. They perceive that contacting the police in the case of a crash is important. They self-asses their certainty level in answering the questionnaire as high. They rank 3/4 items in ***accessibility*** and 2/4 items in ***tangibles*** as of medium/high importance, rank 5/5 items in ***responsiveness*** and 4/4 items in ***fairness*** as of high importance, and rank 4/4 items in ***caring*** as of low importance.

Table 3. Latent class characteristics (percentage of cluster observation)

Variable	Category	C1	C2	C3	C4	C5	C6	C7
Percentages of the observations		10	17	16	13	2	17	23
Person characteristics								
Gender	Male	45	86	50	64	97	20	75
Age group	18-29	0	13	0	27	47	13	10
	30-39	11	33	43	0	2	46	15
	40-49	33	13	36	45	48	7	10
	50-59	33	33	14	27	2	20	35
	60+	22	7	7	0	1	13	30
Work place (region)	Zealand	88	47	71	64	97	47	45
	South Denmark	11	40	0	9	1	27	30
	North/Mid Jutland	0	13	29	27	1	27	25
Stakeholder group	Research	55	0	36	0	48	13	10
	Consultant	11	40	21	72	2	14	45
	Authority	33	60	29	28	50	60	40
	Supplier + NGO	0	0	14	0	0	13	5
Safety and data knowledge								
Worked with black spot and crash analysis	Yes	55	80	1	81	3	40	60
Read documentation of traffic crashes	Yes	67	100	43	82	51	67	75
Wrote crash reports	Yes	44	40	0	36	49	27	25
Interest in traffic safety	Yes	78	100	86	100	53	93	100
Worked with traffic safety-inspections and revisions	Yes	1	66	0	72	49	27	40
Worked with traffic safety planning and safe roads	Yes	12	86	15	63	50	34	75
Police	Visited	33	33	21	45	49	27	25
Contact to police	Not important	0	0	14	0	47	7	20
	Don't know	33	27	21	18	1	7	30
	Important	67	73	64	82	51	87	50
Knowledge about the police								
Certainty level	Very low	33	0	28	0	1	27	15
	Low	22	13	28	27	48	7	15
	Medium	44	40	15	54	2	20	50
	High	0	40	29	18	2	40	20
	Very High	0	7	0	0	47	7	0
Dimensions for reporting								
The travel time by car from home to the police station is short	Low importance	66	80	22	19	3	34	80
	Medium importance	22	20	36	45	2	60	20
	High importance	11	0	43	36	94	7	0
Contacting the police is easy for reporting a traffic crash	Low importance	11	33	0	0	48	0	60
	Medium importance	44	40	22	36	3	73	25
	High importance	44	27	78	63	49	27	15
The police answers the telephone in a timely manner	Low importance	11	27	0	0	48	0	55
	Medium importance	44	40	29	18	2	73	25
	High importance	44	33	71	81	50	27	20
The police arrives to the crash scene in a timely manner	Low importance	0	27	0	0	48	0	50
	Medium importance	44	33	29	45	3	73	25
	High importance	55	40	71	54	50	27	25
The police stations have nice	Low importance	34	53	64	81	97	14	65

and clean waiting areas	Medium importance	44	47	36	1	3	86	30
	High importance	22	0	0	18	0	0	5
The police stations have quiet and relaxing indoor environments	Low importance	23	47	57	81	97	0	65
	Medium importance	55	53	43	1	3	93	25
	High importance	22	0	0	18	1	7	10
The computer recording of traffic crashes at the police is easy	Low importance	0	0	29	9	94	0	40
	Medium importance	44	40	57	63	3	60	5
	High importance	55	60	14	27	3	40	55
The police has electronic resources for correct registration of crash reports	Low importance	22	0	36	36	95	0	40
	Medium importance	23	33	43	54	3	73	25
	High importance	55	66	21	9	2	27	35
The waiting time at police stations is short when reporting a traffic crash	Low importance	0	13	7	0	94	0	0
	Medium importance	22	33	22	27	2	80	20
	High importance	78	53	71	73	4	20	80
The police provides a prompt service when reporting a traffic crash	Low importance	0	0	0	0	93	0	0
	Medium importance	22	20	14	27	2	73	10
	High importance	78	80	86	73	5	27	90
The police provides good information to facilitate crash reporting	Low importance	0	0	0	0	93	0	0
	Medium importance	44	20	7	36	2	86	0
	High importance	56	80	93	64	5	14	100
The police resolve problems effectively related to crash reporting	Low importance	11	0	0	0	94	0	0
	Medium importance	11	20	7	18	2	79	5
	High importance	78	80	93	82	5	21	95
The police allocates suffcient time for people who need to report a traffic crash	Low importance	0	0	0	0	93	0	0
	Medium importance	33	7	14	27	2	79	0
	High importance	67	93	86	73	5	20	100
The police officers are generally friendly and smiling	Low importance	11	73	0	9	48	0	5
	Medium importance	34	27	36	45	3	99	35
	High importance	55	0	64	45	49	0	60
The police officers treat people who report traffic crashes with respect	Low importance	0	33	0	0	47	0	0
	Medium importance	33	47	15	54	3	99	0
	High importance	66	20	85	46	50	1	100
The police officers help people feel safe	Low importance	11	53	0	9	48	7	5
	Medium importance	23	47	36	54	3	86	25
	High importance	66	0	64	36	49	7	70
The police officers understand people's needs	Low importance	11	26	0	18	47	0	0
	Medium importance	1	66	29	45	3	93	5
	High importance	88	7	71	37	50	7	95
There are police officers specialized in handling traffic crash reporting	Low importance	88	7	7	45	2	13	20
	Medium importance	12	40	50	55	3	86	30
	High importance	0	53	43	0	95	0	50
The police officers remain neutral and fair	Low importance	99	7	0	27	1	0	0
	Medium importance	1	20	14	72	2	93	5
	High importance	1	73	85	1	97	7	95
The police officers record traffic crashes correctly and precisely	Low importance	66	0	0	9	47	0	0
	Medium importance	33	0	14	63	2	80	0
	High importance	1	100	86	28	51	20	100
The police officers dedicate time for traffic crash reporting	Low importance	77	0	0	18	47	0	0
	Medium importance	22	27	29	81	2	80	5
	High importance	1	73	71	1	50	20	95

C3 is a cluster of professionals age 30-49 years old, who mainly work in Zealand. They have an interest in traffic safety but most of them have no working experience in the safety field beside reading safety reports. They perceive that contacting the police in the case of a crash is important. They self-asses their certainty level in answering the questionnaire as low. They rank 4/4 items in ***accessibility***, 5/5 items in ***responsiveness***, 4/4 items in ***fairness*** and 4/4 items in ***caring*** as of high importance, and rank 4/4 items in ***tangibles*** as of low/medium importance.

Cluster C4 is a cluster of professionals age 40-59 years old, mainly males who work as consultants in Zealand. They have experience with both office and field work in traffic safety, because they have extensive experience with both reading and analysing safety reports and traffic safety inspections, revisions and planning. Most of them have experience with analysing crash data and black-spots. They perceive that contacting the police in the case of a crash is important. They self-asses their certainty level in answering the questionnaire as medium. They rank 3/4 items in ***accessibility*** as of medium/high and the remaining item as of high importance, 5/5 items in ***responsiveness*** as of high importance, and 4/4 items in ***caring*** as medium/high importance, 4/4 items in ***fairness*** as of medium importance, and 4/4 items in ***tangibles*** as of low importance.

Cluster C5 includes only two respondents with a difference of opinions, and hence the results of cluster C5 are not discussed.

Cluster C6 is a cluster of female professionals, who work in authorities. Their main experience is in reading reports. They perceive that contacting the police in the case of a crash is important. They self-asses their certainty level in answering the questionnaire as medium. They rank all the items across all the dimensions as having medium importance.

Table 4. The possibility for improving traffic crash reporting (percentage of the cluster observations)

Possibilities for improving in the police	C1	C2	C3	C4	C5	C6	C7	Total sample
Low	12	0	7	0	50	7	20	9.3
Some	22	20	36	9	0	7	40	23.3
Partly	44	33	36	64	0	40	25	37.2
High	22	27	21	18	0	46	15	24.4
Very high	0	20	0	9	50	0	0	5.8

Cluster C7 is a cluster of professionals over 50, mainly males who work in consultancy and authorities. Their main experience is with traffic safety planning and safe roads and reading safety reports. Only 50% of the members of this cluster think that contacting the police in the case of a crash is important. They self-asses their certainty level in answering the questionnaire as medium/high. They rank 4/4 items in ***accessibility*** and 2/4 items in ***tangibles*** as of low or medium/low importance, 5/5

items in ***responsiveness*** and 4/4 items in ***caring***, and 3/4 items in ***fairness*** as of high importance.

4.4 The Possibility to Increase the Reporting Rate

The distribution of the stakeholders' perceptions of possible improvement in the police for handling traffic crash reporting as an overall estimate given for each cluster is shown in Table 4 together with the total sample percentages. Table 5 lists the perceived increase in the crash reporting rate to the police, provided the necessary improvements along each quality of service dimension.

Table 5. The perceived increase in crash reporting rate to the police, provided service quality improvement along the specified dimensions (percentage of the cluster observations)

Dimensions	Increase in the reporting rate	C1	C2	C3	C4	C5	C6	C7	Total Sample
Accessibility	Very low	33	66	21	0	0	20	65	37.2
	Low	12	7	7	28	50	13	15	14.0
	Medium	33	27	43	36	50	27	10	27.9
	High	22	0	21	36	0	40	5	18.6
	Very high	0	0	8	0	0	0	5	2.3
Tangibles	Very low	11	27	29	27	0	13	55	29.1
	Low	33	20	29	19	50	20	15	22.1
	Medium	44	27	36	45	50	13	5	25.6
	High	12	20	0	9	0	40	20	17.4
	Very high	0	6	6	0	0	14	5	5.8
Responsiveness	Very low	45	13	21	18	50	20	30	24.4
	Low	11	7	22	27	0	20	20	17.4
	Medium	0	33	14	45	0	20	25	23.3
	High	11	40	43	10	0	27	20	25.6
	Very high	33	7	0	0	50	13	5	9.3
Caring	Very low	22	47	14	19	50	27	40	30.2
	Low	33	13	14	45	0	27	30	25.6
	Medium	22	40	22	36	50	12	15	24.4
	High	22	0	50	0	0	27	10	17.4
	Very high	0	0	0	0	0	7	5	2.3
Fairness	Very low	44	40	14	36	0	34	45	34.9
	Low	11	0	7	36	50	20	20	16.3
	Medium	33	47	29	18	50	13	25	27.9
	High	12	13	50	10	0	20	5	17.4
	Very high	0	0	0	0	0	13	5	3.5

Looking at the whole sample, 30.2% of the experts perceive that improving the crash reporting rate is highly possible, while only 9.3% believe that the possibility for increasing the reporting rate is low. At the cluster level, cluster C2 is the most

optimistic among the clusters, followed by cluster 6. Cluster 7 is the most pessimistic regarding the possibility to improve the existing reporting rate.

Looking at the whole sample, across all the dimensions, 20-30% of the experts perceive that an improvement in a particular dimension will be associated with an increase of the crash reporting rate. The most promising dimension is ***responsiveness*** (35% of the experts associate it with a high increase in the reporting rate), while the least promising seems to be ***accessibility*** (37% of the experts associate it with a low increase in the crash reporting rate).

Looking at the difference across clusters, a higher share of the experts in cluster C2 and C7 associate ***accessibility*** with a low increase in the crash reporting, while a higher share of the experts in clusters C4 and C6 associate ***accessibility*** with a high increase in the reporting rate. A higher percent of the experts in C6 associate ***tangibles*** with a high increase in the response rate compared to the other clusters. Compared to the total sample, higher share of the experts in cluster C2 and C3 associate ***responsiveness*** with a high increase in the reporting rate. A higher share of the experts in cluster C3 and C6 associate caring with a high increase in the reporting rate. Compared to the total sample, a higher share of the experts in cluster C2 and C3 associate ***fairness*** with a medium and high increase in the reporting rate, respectively, while a higher share in cluster C7 associate ***fairness*** with a low increase in the reporting rate.

5. Conclusion

This study focused on service quality within the police and on their handling of traffic crash reporting. Framed around the SERVQUAL scale, we investigated the opportunities and the barriers for the handling of traffic crash reporting based on an expert MCDA technique combined with the LCA approach. For that reason, it highlights where improvements should be made in order to benefit the reporting rate the most. The results also provide more information and extend findings about service quality within the police (Mastrofski, 1999; Donnelly et al., 2006; Chu et al., 2010; Maguire & Johnson, 2010; Akhtar et al., 2011). Furthermore, the study presents a new framework to evaluate service quality in other fields.

We have proposed a new approach that has successfully been applied for the purpose of eliciting stakeholder perceived importance on the handling of crash reporting within the police. The results show that, in general, there is quite a high satisfaction with the service quality in the current situation. The dimension ***caring*** scores the highest, mostly because the Danish society is connected with a high social trust to the police. Maybe this result could appeal to other countries to explore the transferability of the Danish communication model in handling traffic crash reporting more deeply. In general, the stakeholders participating in this study view human factors (e.g. communication, interaction) as more important in order to increase the reporting rate than physical factors. For that reason, the overall results show that stakeholders' perceived ***responsiveness***, ***caring*** and ***fairness*** as more important than ***tangibles*** and ***accessibility***. Hence, although human factors scored quite high for the current situation

of the police service in handling crash reporting, the results highlight the need for further improvements.

According to the clustering results we found that, according to stakeholders' characteristics, professional and personal experience the perceptions regarding the importance of handling traffic crash reporting are viewed differently. This means that the stakeholders' opinion on where and how much to invest in the different dimensions are not perceived the same. For example, it was found that the cluster which perceived the possibilities for a high improvement of the reporting rate mostly within ***accessibility*** and ***tangibles*** mainly consists of females working as authorities. Nevertheless, the experts across clusters agree that ***responsiveness*** is the most important dimension to be improved and that it will yield higher crash reporting rates. In addition, besides cluster 7 that considers only human factors as important, all the other clusters see the necessary improvements as a mixture of human factors with physical factors and the two cannot be separated.

The proposed method to evaluate service quality where some of the advantages are the possibilities of weighting the improvement rates, the reflection procedure, and the ability to represent overlap across clusters in the clustering part. The method demonstrates the usefulness of the tool even in countries connected with a high police service quality and opens up for possible new results for service quality evaluations. A further research direction could be the application of the proposed method, with necessary adaptation, also for other service fields combining physical facilities and human interaction such as the aviation industry, tourism, and public transport provision.

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